4D BIM ADOPTION

THE INCENTIVES FOR AND BARRIERS TO 4D BIM ADOPTION WITHIN SWEDISH CONSTRUCTION COMPANIES

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Sweden is perceived to be one of the Building Information Modeling (BIM) leaders in the world. However, studies have shown that 4D BIM, which is a combination of a 3D model and an associated time schedule, is not widely deployed in construction planning practices among contractors. In Sweden many studies focused on BIM adoption in general, but since contractors are the main users of 4D BIM, there is a lack of studies exploring this specific dimension of BIM. This study considers 4D BIM as an innovation; the aim is to find the incentives for and barriers to adopt 4D BIM within the Swedish construction industry. A literature review was conducted and the most common variables were derived; in addition to this, an online questionnaire and a series of interviews targeting Swedish construction companies were conducted. The findings were that 4D BIM is a new start within the Swedish construction industry, where a series of both technical (software, standards, complexity) and non-technical barrier (organizational, lack of client demand, unclear benefits, investment) has an impact on the adoption process. Large companies are the early adopters and use it to maintain their strategic position in the industry, whereas smaller contractors are prone to more barriers and mostly rely on clients´ demand.
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Acronyms

AEC   Architecture, Engineering, Construction
AIA   American Institute of Architects
BIM   Building Information Modelling
CAD   Computer Aided Design
CPM   Critical Path Method
DB    Design Build
DBB   Design Bid Build
DIT   Diffusion of Innovation Theory
ICT   Information and Communication Technology
IFC   Industry Foundation Classes
IT    Information Technology
IPD   Integrated Project Delivery
LBP   Location Based Planning
LOD   Level of Detail
LOI   Level of Information
NBS   National BIM Specification
RFI   Request for Information
ROI   Return on Investment
2D    Two dimensions
3D    Three dimensions
4D    Four dimensions
5D    Five dimensions
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Chapter 1: Introduction

The construction industry in Sweden represents approximately 5.7% of the total gross domestic product (GDP) of its economy, with USD 7.4 billion in the fourth quarter of 2017 (Trading Economic 2018). Additionally, around 3% of total greenhouse emissions are produced by this industry which is mainly from transportation and the operation of construction equipment/machinery (SCB 2018). In the U.S, 30% of projects are not delivered within their time frame and budget, 92% of clients are dissatisfied with the amount of drawings provided by architects for construction (CMAA 2005; 2007 cited by Tommasi and Achille 2017), 5.3% of the project cost are increased as a result of change orders (AACE, 2004 cited by Tommasi and Achille 2017) and 37% of material used in this industry becomes waste (Economist Magazine, 2002 cited by Tommasi and Achille 2017). The heterogeneous nature of the construction industry makes a construction project characterized as complex (Sears et al. 2015) having a fragmented and unique nature (Kassem et al. 2012; Boton et al. 2013) and being criticized for its poor performance in managing time, cost, safety and quality (Kanji and Alfred 1998; Tommasi and Achille 2017). The recent revolution in Information and Communication Technology (ICT) has benefited this industry in many ways which in turn enhanced the productivity (Johnson and Laeppele 2003). Building Information Modelling (BIM) is one of the examples of recent advancements which have emerged due to the inefficiencies that existed in planning and production phases (Tommasi and Achille 2017). BIM is labelled as a potential standard which brings all involved parties of a project together (Azhar 2011), while, functioning differently for each discipline (Eastman at al. 2011). Scandinavian countries are considered as the front runners in BIM adoption (Khosrowshahi and Arayici 2012; Smith 2014). In Sweden, one of the largest public sectors (Swedish Transportation Authority) mandated BIM use in 2015 (Trafikanalys 2015) this has helped the larger companies to take the initiative in using BIM and implement BIM manuals during design procurement (Skanska 2014 cited by Hooper 2015). Nevertheless, projects are still frequently critiqued for not keeping to schedules and budgets. The time and cost overrun that usually arise during the actual execution phase are partially due to unrealistic estimates and calculations (Hallin and Karrbom Gustavsson 2012). Even though, the time and cost management as part of the whole construction process is not overlooked in the latest 4-dimension and 5-dimension of BIM. Studies show that the time dimension (4D BIM) is not widely deployed (Hallberg and Tarandi 2011; Merschbrock and Munkvold 2015). This indicates that the wide range of 3D BIM models did not affect the industry to change from traditional construction planning method to 4D BIM. Meanwhile, 4D BIM is perceived as one of the key tools to enhance efficiency by reducing waste and increase value for construction project customers (Rolfesen and Merschbrock 2016).

1.1. Problem statement

Large construction companies have realized the value of BIM to an extent and have started using it both in their design phase and in production phase for construction planning (Franco et al. 2015). They consider it as a tool to manage both design and production phases by linking the time (4D) and cost (5D) dimensions to a 3D solid model, while smaller companies
are likely to perceive BIM as 3D modelling only (Ghaffarianhoseini et al. 2017). In fact, due to the limited access of smaller companies to BIM, they are mostly suffering from lack of experience (Ghaffarianhoseini et al. 2017). Besides, they lack incentives to produce BIM models on their own when it is not demanded by the client (Franco et al. 2015). Now, several questions emerge; do all Swedish construction companies not use 4D BIM in their current construction planning practices? If not, what are the reasons? Do they still prefer traditional construction planning? By not using it, do they miss some of the potential benefits which 4D BIM offers? If they are using it, how much are they satisfied with? How many large companies are using it? What are the incentives and barriers for them? Do they use it in all of their projects? If not, why? How are decisions made in order to adopt/not adopt 4D BIM? These questions motivated this study because the earlier studies were either in favor of large companies and or about BIM in general. This study will explore all sized companies; small, medium-sized and large, and the focus will be on 4D BIM in construction phase.

1.2. Purpose

This study aims to explore the current status of 4D BIM adoption and the main barriers to and incentives for 4D BIM adoption within Swedish construction companies. In order to meet the aim of this research, the following objectives were set:

**Objective 1:** To find out the level of 4D BIM usage, the perceived qualities and advantages of 4D BIM over traditional construction planning approaches within Swedish construction companies.

**Objective 2:** To explore the possible incentives, limitations and drivers that influence 4D BIM use within Swedish construction companies.

1.3. Research question

This study will answer the following question and sub-questions:

“What are the incentives for and barriers to 4D BIM adoption within Swedish construction companies?”

- How much are the construction professionals familiar with 4D BIM?
- How do construction professionals perceive 4D BIM over traditional methods?
- To what extent are they using it?
- Why have they decided to use it (incentives)? Or why have they not (barriers)?
- What are the best solutions to overcome the barriers and promote 4D BIM?

1.4. Limitation

This study is limited to construction companies or contractors which are involved physically in production phase. Consultancy and project management companies are beyond the scope of this study. Furthermore, the focus will be on production phase. The primary data in this study will be entirely collected in Sweden and from Swedish firms.
Chapter 2: Methodology

This chapter describes how this study has been carried out. It helps the readers understand the overall four and a half months study process. But, the focus will be on the data collection process, the validity and reliability threats to the findings and conclusion; and finally how the research ethics has been considered in this study.

2.1. Research approach

To construct a conclusion, two alternatives can be used to demonstrate what is true and what is not. These alternatives are induction and deduction. In this case the induction can be proved through empirical evidences, while the deduction is done through logic (Ghauri and Grønhaug 2010). This study is an explorative research using the deductive approach. This approach usually starts with a basic statement or theory and progresses to observation and confirmation. It will allow the author to construct conclusions from the primary and secondary data which will be collected, and to expand the knowledge about the adoption of 4D BIM within Swedish construction companies.

2.2. Data collection method

All data collection methods fall into two main groups, namely; quantitative and qualitative. One way to differentiate them is that the quantitative method deals more with numeric data while the qualitative method deals more with non-numeric data (Saunders et al. 2009). Since this research is exploratory, a mixed method approach is deployed. First, the literature study is conducted to identify the main barriers and incentives influencing the adoption of 4D BIM. Next, the quantitative data are collected through an online questionnaire that forms the basic part of findings. The qualitative data is collected through interviews to supplement quantitative data and provide a deeper understanding on factors that influence 4D BIM adoption.

2.3. Literature study

In order to establish a theoretical basis and obtain a deeper knowledge about 4D BIM, the incentives and barriers to its adoption, a literature study was conducted. The sources for literature study were mainly from textbooks, academic journals and some online sources. The aim was to first deepen my knowledge in the subject area and secondly to use it as a strong foundation in designing the online questionnaire. The subjects covered under this literature study are; the concept of BIM, 4D BIM, benefits of 4D BIM and challenges for 4D BIM implementation.

2.4. Empirical data

The collection of secondary data through literature study provides a base to collect primary/empirical data. The empirical data is collected through an online questionnaire and supplemented by semi-structured interviews.
2.4.1. Online questionnaire

In order to measure the barriers to and incentives for 4D BIM adoption, the online questionnaire was designed with six sets of questions. The first set was aimed to collect demographic information of the participants followed by examining the perceived advantages and perceived attributes of 4D BIM. The last three sets were dedicated to examine the 4D BIM use, the barriers to and the incentives/drivers for 4D BIM adoption. The preliminary version of the online questionnaire was discussed with my supervisor and the necessary changes have been made. Upon final review by supervisor and test by potential respondents, the final version was sent to 40 construction companies. 12 small (1-49 employees), 22 medium sized (50-500 employees) and 6 large (500+ employees). In response 26 companies responded (5 small, 15 medium-sized and 6 large) with a total response rate of 65%. The sizes of companies were chosen based on the Swedish Construction Federation’s classification. The aim of quantitative data was to capture the demographic profile of the participants and to find out the most prominent influential factors that hit the 4D BIM adoption process. The sample of questionnaire can be found in Appendix I

2.4.2. Interviews

The interviews were conducted for two reasons. First, to enhance my knowledge and obtain deeper perceptions from construction experts about 4D BIM adoption in Sweden. Second, to supplement and re-verify the validity of quantitative data. Seven semi-structured interviews were conducted within a period of two weeks, three from representatives of medium-sized companies and four from large companies. The interview questions were formulated based on the responses received through quantitative survey and covered topics about 4D BIM use, the qualities associated with 4D BIM, the barriers to and incentive for using 4D BIM and finally the solutions to overcome these barriers. The interviews were conducted both face-to-face and on the phone. The language used in interviews was English and all interviewees were fluent, however some Swedish concepts were raised by some interviewees, which were later interpreted by them in English. So, in general, language was not a barrier during data collection. The sample of basic interview questions can be found in Appendix II

2.5. Findings and discussion

The findings chapter presents the results of both quantitative and qualitative data. The results are presented separately and are structured based on two study objectives. First, descriptive statistics findings are presented using SPSS statistical analysis software. Secondly, the coding of responses method is used for analyzing qualitative data and all important points which were emphasized more or repeated during the interviews were categorized and presented. In the discussion section both qualitative and quantitative data are compared and the causes and effects of variables are further discussed. Furthermore each of these relationships is reflected with theories presented in the theoretical and conceptual framework.
2.6. Research ethics

It is very important to take research ethics into consideration. All phases of this study were carried out in a way that it does not harm, embrace or coerce anybody who is participating in this study. The consent of data was strictly considered in both formal and implied forms during interviews and online questionnaire. The participants were informed about the research topic, the research objectives and how their participation contributes to the study. Additionally, interviewees were asked for permission of recording their voices to ensure the efficiency and quality of responses is monitored. The interviewees and surveyed participants’ identity and their company names are entirely anonymous but they are presented based on their professional positions and their company sizes just for comparison purposes.

2.7. Validity and reliability

The value of this study can be affected by validity and reliability of the acquired data. The validity of data is observed while collecting both qualitative and quantitative data. As stated in empirical data section that there were threats to reliability of the collected quantitative data due to the small sample size, therefore one of the reasons to conduct interviews was to enhance the validity and reliability of collected data so that a precise conclusion can be drawn.
Chapter 3: Theoretical and Conceptual Framework

This chapter introduces the relevant theories used in this study, followed by elaborating the most important concepts linked to BIM. Moreover, the findings (benefits and challenges) of the conducted literature study are presented in relation to the research problem in the end of this chapter. The theories, concepts and findings of the literature study are used as a base for data collection and will be further reflected in the discussion chapter.

3.1. Theories

3.1.1. Diffusion of Innovation Theory (DIT)

In order to find the incentives and barriers that influence the 4D BIM adoption process, Rogers (2003) diffusion of innovation theory will be used as being one part of the theoretical framework. The innovation diffusion theory describes how a product or an idea spreads over time among a specific segment of people. To make the diffusion possible, each individual in this segment has to perceive the new product or idea as groundbreaking or new (LaMorte 2016). Thus, the differences in perception of individuals on the characteristics of the product or idea have a direct impact on the adoption of the innovation (Gledson and Greenwood 2017). Therefore, the perceived characteristics of the innovation (4D BIM) can help to identify the status of its adoption. Rogers (2003) Diffusion of Innovation (DIT) asserts that:

“Innovations that are perceived by individuals as having greater relative advantage, compatibility, trialability, and observability and less complexity will be adopted more rapidly than other innovations” (Rogers 2003)

The “relative advantages” is quoted as “the degree to which an innovation is perceived as better than the idea that it supersedes” (Rogers 2003). In this case, complexity is defined as the relative amount of efforts required to use 4D BIM. Compatibility is defined as the availability of the required experience and the resources for potential adopters to easily adopt 4D BIM innovation. Trialability refers to having the chance to try and test 4D BIM innovation before using it and observability specifies if the impacts of using 4D BIM are easy to see.

3.1.2. Institutional Theory

Institutional theory describes the stability and transformation of institutions (DiMaggio and Powell 1983; Sæbø 2017). Based on the institutional theory, there are three types of pressures that influence institutions to become isomorphic (become the same), namely; normative, mimetic and coercive (Cao et al. 2014). The normative pressure refers to professional bodies within a specific field, developing shared norms for an organization. The mimetic pressure arises from uncertainty. For example, technological innovations are uncertain, so companies imitate or model their organizations based on other successful organization procedures and methods (Sæbø 2017). The coercive pressure indicates when an organization comes under pressure of other powerful organization they are affiliated with (Co et al. 2014). For example, when the public sector changes requirements, the contractor comes under pressure to change their methodology.
3.2. Construction planning

Construction planning plays a key role in the development of the construction industry (Allen and Smallwood 2008). It is essential to define the required time against the performance of a project (Gledson and Greenwood 2016). The aim of this process is to define the activities, their dependencies and thus to make sure it is performed efficiently, safely and environmentally-friendly (Zanen and Hartmann 2010). There has been several construction planning methods carried out in advanced construction industry. The most common are Gantt chart, Location Based Planning and Critical Path Method (CPM). The Gantt chart method illustrates activities with their period. It also shows the actual versus the planned performance of each activity. Although, this method is popular, but it is repeatedly criticized due to poor function in describing the impact of activities on each other and the effect of delays. (Nunnally 2007) Upon arrival of the critical path method, this gap has been filled. The appropriate model of this method not only shows the relationship between activities but also the work breakdown structure, the estimation of activities duration and dependencies among them are further developed (PMI 2013). However, the CPM has also been criticized for the poor resource utilization and failing to cope with those similar activities which are planned parallel but in two different locations of a construction site which as a result, disrupts the construction process. Consequently, Location Based Planning emerged in the mid-20th century (Andersson and Christensen 2007). The aim of this method is to keep the construction resources working constantly during the lifespan of a project without interruption and conflicts among repetitive activities (Nunnally, 2007). However, this method demands more input information in the earlier stage of construction (Andersson and Christensen 2007). Finally, the recent evolution in information technology, the 4-Dimesion Building Information Model (4D BIM) developed. This method allows planners to visualize activities connected to the 3D model objects (Eastman et al. 2011).

3.3. The concept of BIM

The BIM concept was initially introduced in early 2000 (Volk et al. 2014). The basic idea was to add additional information such as properties, materials and other data to the 3D functional design produced by architects and engineers. Upon the emergence of BIM in the construction industry, the aim was to enhance efficiency whilst reducing the costs and supporting the management of the entire construction stages (Sucar 2009).

The basic theory behind BIM is well defined by Miettinen and Paavola (2014). BIM is a group of technologies and solutions aiming to improve collaboration and enhance productivity of pre-construction, construction and post-construction practices. BIM technologies are constantly growing and advancing new functionalities. 3D BIM offers satisfactory visualization benefits, whereas 4D model provides knowledge about different requirements across the lifespan of a project. (Ghaffarianhoseini et al. 2017). When developing such models for a project, most stakeholders are integrated and work jointly in earlier phases than in the traditional way. The U.S. National Building Information Model Standard (NBIMS) further defined BIM as: “a digital representation of physical and functional characteristics of a facility. A building information model is a shared knowledge
3.4. BIM functions and usage

Every project uses different functions of BIM based on the nature and needs of a project. Every function of BIM can store a variety of information to be shared and at the same time a variety of information can be retrieved from it (NBIMS 2018). BIM can be used from the early conception or initiation phase on, to the demolition phase. Therefore, it is important to identify the basic categories that BIM is used for. BIM application can be categorized based on different cases and applications, e.g. generic and practical. According to Cao et al. (2014), there are different applications of BIM in planning and construction phases. In the project planning phase, it is used for site analysis, analyzing design, 3D presentation, design coordination, cost estimation, clash detection, energy and other performance simulations. While, in the production phase, it is usually used for construction planning or 4D simulation, quantity take off, logistics planning and fabrication (Cao et al. 2014).

3.5. Dimensions of BIM

BIM can be dimensionally described based on the availability of information and its connectedness. The 3D refers to the three spatial dimensions (xyz) for visualization, while the 4D is the addition of time and the 5D adds the cost dimension to the BIM model (Kymmell. 2008; Ghaffarianhoseini et al. 2017). The traditional classification of BIM use includes 3D, 4D, 5D, right up to nD, where the definition of nD is related to the classification of the type of information that can be generated and the related outcomes can be used for different purposes (Ghaffarianhoseini et al. 2017).

3.5.1. 3D model

The 3D BIM model comprises spatial relationships, geographic and geometric information (x,y,z) of a building element. This model is capable to be used for data retrieval and transfer; simulation and analysis; and visualization which support better communication and coordination (Bosch-Sijtsema et al. 2017). It provides a more accurate visualization of the design for all involved stakeholders, which in turn improves the graphical design verification. Moreover, the virtual design and construction (VDC) offers good knowledge sharing benefits that can enhance the satisfaction level of the clients. (Ghaffarianhoseini et al. 2017) All of the capabilities offered by this model are retrieved by two basic characteristics e.g. object-based information and x,y,z coordinates that helps to simply triangulate the geometric location of each object in the design space (Bosch-Sijtsema et al. 2017). The clash detection of design helps to eliminate clashes before actual construction begins, leading to a reduction of the number of request for information (RFI) – less change orders (Ghaffarianhoseini et al. 2017) and thus supports an efficient construction process with lower costs and lower potential of legal disputes (Eastman et al, 2011).
3.5.2. 4D model

A project’s efficiency can be enhanced by improving the production rate and repetitive activities (Kymmell 2008). 4D model refers to linking the construction time plan to the 3D model (Eastman et al. 2011). Since 4D model generates construction process visualization, it is acknowledged as the key benefit of BIM in planning construction projects (Hallberg and Tarandi 2011; Hartmann and Vossebeld 2013). 4D BIM tools help project planners to communicate visually in planning activities throughout the time and space framework (Eastman et al. 2011). This in turn can help to reduce the transactional gap between stakeholders during the production phase (Gledson and Greenwood 2017). The information contained in this model also includes the production rate which can be used for better schedule analysis and configuration of the activities by considering their location and production rate.

3.5.3. 5D model

The extended 4D model with the addition of cost information is called 5D BIM (Eastman et al. 2011). 5D BIM has the capability to predict and track the costs of a project throughout the entire construction stages. During any design stage, this model allows to estimate and evaluate different design options cost wisely. Furthermore, it simplifies the calculation of all kind of quantities such as quantities related to dimensions of BIM (including time), engineering and technical quantities and finally, generates the bill of quantities and cost related information (Xu 2017). The retrieved data from this model can be used to assess if the financial aspect of a project is of interest during the production phase of a project (Kymmell, 2008).

3.6. 4D BIM process and functions

The 4D BIM, which is also known as 4D planning, integrates the construction schedule as the 4th dimension to the 3D model (Eastman et al. 2011). This information allows to graphically visualize the construction process throughout a single model (Staub-French and Khanzode 2007; Kassem et al. 2012). In general, the 4D construction planning process includes setting up and sequencing the construction activities by considering time and space. Factors such as space coordinates, logistics and procurement which have a direct impact on the construction process are also deliberated in 4D planning process. Whereas, in the traditional construction planning methods e.g. Gantt Chart and Critical Path Method (CPM) are lacking the spatial capabilities and the feature to link activities to 3D model elements$. The 3D model and the simulation of the time dimension enables project organizations to detect and fix issues that arise in construction sequencing, procurement and in the field. Adding temporal elements (e.g. crane, scaffolds, equipment) into the model can help to reduce the field interferences that might arise during the execution phase, which in turn improves the buildability (Staub-French and Khanzode 2017; Boton et al. 2015). For this, the contractor’s knowledge and feedback in 4D planning is significantly important (Baton et al. 2015). Nowadays, the advanced 4D planning computerized tools simplify the 4D BIM model creation procedure. These tools are able to associate 4D with the three-dimensional building objects automatically. It also allows...
planners to generate, evaluate and modify 4D models in a more precise way and to apply them in a higher quality (Eastman et al. 2011). Despite these benefits, the application of 4D planning in an actual multidisciplinary project is a complex process. Therefore, a joint effort is needed to overcome this challenge (Staub-French and Khanzode 2017). Gledson and Greenwood (2015) identified the following 4D planning functions. These functions refer to the outcome of a construction planning process.

- Visualizing the construction progress over time
- Simplifying understanding of the construction flow
- Logistics planning (equipment and material flow within the construction site)
- Planning and coordinating working space
- Planning construction methods (comparison of execution plans)
- Site layout planning
- Location-based planning
- Validation and analysis of the time schedule
- Design investigation
- Work-progress reporting
- Safety planning (scaffold; crane)

3.7. Adoption of 4D BIM

Despite the benefits 4D BIM has to offer, the organizational and inter-project challenges has weakened the adoption of 4D BIM innovation. Therefore, it will be difficult to adopt 4D BIM, unless it is integrated within current construction planning methods. (Mahalingam et al. 2010) In addition, people’s resistance to change is perceived as another factor that hinders 4D BIM adoption (Kassem et al. 2012). Other factors such as organizational culture, compatibility, skills, management and technical support have also been noted as main obstacles for the adoption of BIM (Son and Kim 2015). Therefore, understanding the challenges can help to determine the actual status of a technology within an industry (Kassem et al. 2012). Exploring the benefits, value and importance of BIM, as well as the challenges and risks that hinder the adoption of BIM is crucial, since it affects a project from different angles (Franco et al. 2015).

3.8. Benefits/drivers

BIM has evolved to simplify the complication of construction projects by easing the planning, production and operation phases throughout an integrated approach (Ghafrarianhoseini et al. 2017). One of the main contributions of BIM in construction projects is its application in the planning of a project. According to Brito and Ferreira (2015), among the major challenges that project organizations are struggling with are: troubles in visualizing of construction schedules in space, creating abstract schedules that contain interpretation issues. By deploying 4D BIM, the interpretation issues diminished, which made the construction scheduling process more reliable (Koo and Fischer 2000). However, to obtain these benefits, it is
important that all stakeholders within a project develop new skills and apply organizational changes (Staub-French and Khanzode 2007). Bryde et al. (2013) revealed in his 35 project case studies that BIM implementation influenced the time, cost coordination and communication aspects more positively followed by quality aspect of the projects. Furthermore, a case study shows that the capability of 4D BIM in adding the temporal elements (e.g. scaffolds, cranes) into the model enable planners to choose the best construction method and thus avoid the conflicts that might arise during the execution phase (Boton et al. 2015). Several more studies confirmed 4D planning as a beneficial approach to construction planning, where the most common benefits are as follows: 4D BIM

- enhances productivity and reduces RFI (request for information). This in turn helps to avoid re-work and changes in the design (Staub-French and Khanzode 2007);
- allows better visualizing (Hartmann and Vossebeld 2013) and understanding of the construction process (Murguia and Brioso 2017);
- improves communication and simplifies the logistics planning process. At the same time, it helps to analyze and compare different execution plans (Eastman et al. 2011);
- simplifies the analysis of construction schedule in a more advanced way for a better implementation assessment (Koo and Fischer, 2000; Mahalingam et al. 2010);
- reduces the field interferences that might arise during the execution phase, which in turn improves the buildability (Staub-French and Khanzode 2017; Boton et al. 2015);
- helps in decreasing the scheduling conflicts through evaluation and validation processes (Gledson and Greenwood 2016);
- effectively manages the site-space and resource management (Kassem et al. 2012);
- reduces risk and attracts more workforce to construction projects (Arayici et al. 2009);
- facilitates coordination and evaluation applications (Olde Scholtenhuis et al. 2016).

3.9. Challenges to 4D BIM

“The most significant reasons for not adopting BIM include the lack of demand, cost and interoperability issues” (Ghaffarianhoseini et al. 2017).

To identify the actual position of a technology within an industry, it is important to scrutinize the challenges which impede the application of that technology (Kassem et al. 2015). Understanding the challenges is also significant to initiate strategies to overcome those (Kassem et al. 2015). Despite the variety of benefits that BIM offers (Eastman et al. 2011), there is still a comprehensive shortfall in effective application of BIM. In general, the application of BIM is still struggling with technical, organizational, legal and financial risks (K.-F. Chien et al. 2014). Smaller companies due to their limited involvement in BIM projects, are usually suffering more, and thus lacking experience (Ghaffarianhoseini et al. 2017). Besides, effective application of BIM requires a huge investment in establishing the IT infrastructure, training and other requirements are needed in order to successfully adopt BIM (Ghaffarianhoseini et al. 2017). Moreover, research shows that lack of experience and lack of competent personnel are the most common risks in all levels of BIM and should be taken into account before applying BIM into a project management process (K.-F. Chien et al. 2014). A survey by Eadie et al. (2013) within the UK construction industry shows that BIM is widely
used in the design phase while during construction and post construction it is less frequently used.

“Non-technical barriers, such as the inefficiency to quantify the tangible benefits of BIM and 4D and lack of awareness by stakeholders, especially the clients, are affecting widespread use of BIM and 4D more than the technical barriers”. (Kassem et al. 2012).

Another study carried out by Kassem et al. (2012) within the UK AEC industry, reveals that non-technical barriers has more influence on the extensive adoption of 4D BIM and BIM, than technical barriers. Kassem et al. (2012) concluded that there is a need for comprehensive studies of the non-technical aspects to bridge the gap between the technology, its user and the processes, otherwise utilizing this technology will remain limited. Since there are different schools of thoughts concerning barriers and challenges to 4D BIM adoption in the literature, these are the technical and non-technical barriers which are collectively cited as follows:

- Lack of client demand;
- Lack of knowledge and experience within organizations;
- Difficulty in measuring the benefits;
- Higher costs and lengthier process;
- Organizational resistance to change or incompatibility;
- Conventional project delivery methods;
- Interoperability and lack of standards & guidelines;

3.9.1. Lack of internal and external demand

Public clients are known as change makers in the AEC industry based on their application of BIM (Vass and Gustavsson 2017). BIM supporters believe that by using BIM the challenges of the AEC industry can be vanished (Rezgui et al. 2009; Succar 2009 cited by Vass and Gustavsson 2017). Nevertheless, the actual application of BIM is still a challenging task, as it does not always fulfill the expectations (Dainty et al. 2015 cited by Vass and Gustavsson 2017). This reveals that a gap exists between the optimistic vision of BIM/4D BIM and the actual application in the construction industry. Bosch-Sijtsema et al. (2017) show in their study within Swedish medium-sized construction companies that the lack of clients’ demand and lack of internal organization demand are among the highly ranked constraints of BIM use. The study concluded that the main barriers to BIM adoption within Swedish medium-sized construction firms are due to lack of normative pressure. A report by Mcgraw-Hill Construction demonstrated that 55% of those firms which does not use BIM reasoned that there is lack of requirement from the client side. Furthermore, it was also added to the report, that upon client’s request to apply, the BIM promptly obtain a value to the users. This means that the contractors are more influenced by clients’ demand (Kassem et al. 2012). The lack of clients’ demand in BIM adoption is further described in several studies (Eadie et al. 2013; Vass and Gustavsson 2017; Ghaffarianhoseini et al. 2017).

Holzer (2016) argues that the internal pressure to adopt BIM cannot be effective, unless the top management realizes BIM adoption as an administrative issue and not just as a technical issue. Meanwhile, the external pressure can be the mandates by public sectors such as Dubai
and UK BIM mandates in 2015 and 2016 respectively (Mehran 2016). Clients having a strong position in a project can push the 4D BIM adoption. However, this also requires clients to have sufficient knowledge about the technology so that they can push it into the right direction (Kassem et al. 2012). The National BIM Report 2017 shows the BIM mandate in UK mobilized the industry towards a higher adoption rate (NBS 2017). In Sweden, the Transportation Agency (Trafikverket) mandated BIM in 2015 (Trafikanalys 2015).

3.9.2. Lack of knowledge and experience

A successful adoption of an innovation requires educating the subjected organizations (Arayici et al. 2009). The purpose of 4D BIM is to improve the construction plan knowledge through 4D visualization (Mahalingam et al. 2010; Gledson and Greenwood 2016). 4D planning demands knowledge and expertise of planners in managing the construction phase (Sigalo and König. 2017). One of the crucial factors in deciding to adopt a new technology is the staff experience, since without experts it is impossible to obtain the expected outcomes (Kassem et al. 2012). Challenges linked to skills and competency differences are known as significant barriers to implementation of 4D BIM (Brito and Ferreira 2015). A study within the Chinese construction industry concluded, the lack of education and skills as the major obstacles for adoption of BIM (Xu et al. 2014 cited by Mehran 2016). Furthermore, Abanda et al. (2015) found out in their critical appraisal study of 3D, 4D, 5D BIM software and plugins that 50% and 57% of the respondents considered lack of knowledge and lack of in-house skills respectively as highly significant barriers for the implementation of BIM. Similarly, around 36% of respondents believed that the lack of the client’s knowledge was highly significant and 40% have considered it as moderately significant.

In the meanwhile, realizing 4D BIM benefits requires new skills and organizational changes emerge within all disciplines e.g. clients, designers and contractors (Brito and Ferreira 2015). Abanda et al. (2015) claims that, BIM approach is significantly related to computer knowledge, while most of the on-site personnel executing their daily tasks through traditional practices. This situation generates a collaboration gap. Therefore, it is necessary that BIM knowledge covers both process and technology dimensions. For example, aside from BIM promoting activities, trainings should also focus on how to operate BIM software. Moreover, the lack of awareness as a barrier can be offset by developing BIM knowledge and thus it aids to increase BIM acceptance within the AEC industry (Ahn and Kim 2016). The required training can be obtained from software vendors and consultancy firms, while the costs for these trainings can be offset by the benefits which BIM offers (Eastman et al. 2011). Recently one of the Swedish public sectors started empowering the practices and competences in BIM application as well as demanding BIM in their procurements (Vass and Gustavsson 2017).

3.9.3. Observability, time and cost

The cost measuring difficulties raised doubts concerning BIM benefits and thus become a barrier for the implementation of BIM (Love et al. 2013). The time and cost investment required for training and operating can hinder the adoption of 4D and 5D BIM among
contractors (Franco et al. 2015) Thereby, smaller firms suffer more from the startup costs (Bryde et al. 2013). In the meanwhile, BIM benefits are intangible and hard to quantify (Becerik-Gerber and Rice 2010 cited by Bosch-Sijtsema et al. 2017). The National BIM Specification report (2016) indicates that costs are still the major barrier when it comes to implementing BIM within the U.K. and the Czech Republic. According to Love et al. (2013), two different costs are associated with BIM; direct costs, which refer to operational and application costs, and indirect costs, which are linked to workforce and organization. The benefits for direct costs are quantifiable while for indirect cost there are difficulties in measuring them, because the benefits for both categories are immediate and lengthier respectively. Yet the BIM professionals do not realize the business value of BIM, however, they expect it to be useful in the future (Vass 2015). The time and costs required for IT infrastructure and for education as well as their linkage with intangible benefits are perceived as barriers for the widespread adoption of BIM and 4D BIM (Kassem et al. 2012). A case study carried out by Franco et al. (2015) about the adoption of 4D and 5D BIM concluded that the operational benefits of BIM implementation are outbalancing the challenges time, cost and unexperienced workforce, encouraging subcontractors to tackle them. In, another study conducted by Bosch-Sijtsema et al. (2017), the costs to invest on IT infrastructure and training programs were identified among main barriers to the implementation of BIM. Moreover, observing the advantages of 4D BIM as an added value to the project and organization is more important than just seeing them as common advantages. Thus, investing in 4D BIM use will be doubtful, if the ROI (Return on Investment) is unclear (Kassem et al. 2012). In addition, verifying the adequacy of BIM requires additional time and efforts in order to review BIM data. Therefore, new administrative and design related costs will emerge (Ghafarhossieni et al. 2017). Consequently, a cost benefit analysis is in essential to identify the costs associated with BIM in relation to the benefits it provides (Bryde et al. 2013).

3.9.4. Organizational challenges

“BIM implementation undeniably entails change, and adoption is not going to be easy for those who are uncomfortable with change” (Arayici et al. 2009).

The organizational culture is mainly established and practiced by the members of relevant organization. This culture is inherited, whenever any changes occur in an organization, the impacts can appear in business process, existing technologies and employee’s routines (Arayici et al. 2009). The human’s attitude in deciding to adopt advanced technology leads to the widespread adoption of relevant technology which in turn helps the economic development of the organization (Takim et al. 2013). As a result of change in technology and process, the implementation of BIM will develop the quality of services an organization provides (Arayici et al. 2009). However, changing the working processes e.g. learning new planning tools, leads to a big frustration for planners after they gain adequate experience in conventional methods (Gledson and Greenwood 2017). According to Davis and Songer (2009), organizational culture and human resistance to change are significant barriers that impede the adoption of BIM and IT in construction business. Based on the NBS International Report (2016), over 70% of BIM users and non-users in countries like Denmark, Canada, Czech Republic, the UK and Japan believed that BIM adoption requires changes in their
organizational culture e.g. changes in practices, procedures and workflows. In the United Arab Emirates (UAE), resistance against changing the existing construction practices is considered the second biggest challenge which impedes the adoption of BIM (Mehran 2015). Consequently, to tackle this problem, change management theories and other mechanisms that can synchronize the new processes with old processes in the organization are necessary (Kassem et al. 2012). In addition, to realize the advantages of 4D BIM it is essential that the stakeholders work on new skills and at the same time on organizational changes (Staub-French and Khanzode 2007) as 4D BIM adoption requires a powerful organizational change management approach (Rolfsen and Merschbrock 2016) This process is however lengthier and thus needs cautious adoption such as planning, recruitment and education (Arayici et al. 2009).

3.9.5. Project delivery methods

The technical growth of BIM generates new opportunities and connections among stakeholders. As a result, new roles and responsibilities, new form of contracts and procurement methods emerge (Ghafarhossieni et al. 2017). The project procurement or delivery approaches often hamper the project integration. The traditional project delivery methods are not compatible with 4D BIM since integration, collaboration and communication are the main success factors demanded by both 4D BIM and by stakeholders (Kassem et al. 2012). The traditional project delivery method or Design-Bid-Build (DBB) is perceived as ineffective compared to Integrated Project Delivery (IPD) method when using BIM (Eastman et al. 2011). This is because the stakeholders work collaboratively with IPD in earlier phases of a project. Whereas, using the traditional project delivery method the contractors are constrained to add their inputs in the design phase. American Institute of Architects (AIA 2007) defined IPD as “a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication & construction”.

Furthermore, using BIM/4D BIM with Design & Build (DB), which is another project delivery approach (contractor is responsible for both design and construction), is more beneficial, since both construction and design expertise work collaboratively in the design phase. However, these benefits won’t be achieved if the organization is structured based on the conventional method which means designers only deliver the 2D/3D design and the construction team carries out the production phase (Eastman et al. 2011). Additionally, the legal and contractual issues that impede BIM and 4D BIM implementation has been widely acknowledged (Olatunji and Sher 2010; Ashcraft 2008; McAdam 2010; Smith et al. 2011 cited by Kassem et al. 2012). Consequently, Ghafarianhoseini et al. (2017) argues that the integrated nature of BIM raises more concerns regarding liability, security, data ownership and licensing among stakeholders. Therefore a new form of contract is required to cover all stakeholders dealing with BIM or just those who are part of the BIM process.
Technical challenges such as using joint IT platforms and interoperability among software are reported by literature (Bryde et al. 2013). Interoperability as a main feature of BIM allows that BIM related information can be shared effectively among stakeholders using different software (Tommasi and Achille 2017). Despite a huge numbers of software available on the market (Tommasi and Achille 2017; Abanda et al. 2015), there is no tool available to handle all BIM application fields through single software yet (Tommasi and Achille 2017). This further created issues in exchanging information between different disciplines using different software (Steel et al. 2012). The concept of software interoperability according to NIBS is “seamless data exchange at the software level among diverse applications, each of which may have its own internal data structure. Interoperability is achieved by mapping parts of each participating application’s internal data structure to a universal model and vice versa” (NIBS, 2008 cited by Tommasi and Achille 2017). An international institution “BuildingSMART’ has introduced the Industry Foundation Classes (IFC) which is an open standard information exchange format linked to the users, containing both the geometrical information related to building elements, and other dimensions of building e.g. time-based aspects, costs and quantities (Tommasi and Achille 2017). The latest version of IFC is IFC4 that allows incorporation of 4D with project related information (BuildingSMART 2013). It also supports the information exchange related to resources, 4D and 5D BIM (BuildingSMART 2013). However, the basic issue behind interoperability is linked with its huge domain. For example the natures of projects are entirely different e.g. large hospitals, cultural heritage houses, and basic single family house. This has created a gap in interoperability, because there is no single tool to incorporate the entire language for all of these. (Steel et al. 2012) Furthermore, Abanda et al. (2015) found in their critical appraisal study of 122 BIM (3D, 4D and 5D) software and plugins that around 33% of the respondents indicated that the large amount of software available on the market was a significant and crucial barrier in deciding to adopt BIM. Additionally, 51% of the respondents considered the lack of interoperability among tools as very significant and crucial barrier in the BIM implementation. Similarly, in another study by Tommasi and Achille (2017), the practical BIM interoperability was examined and the imperfection of interoperability in complex projects such as cultural heritage buildings has also been revealed. ). Ghaffarianhoseini et al. (2017) concluded in their study of BIM benefits and its current uptake status, interoperability as one of the main reasons that hampers BIM adoption in the construction industry. Consequently, to realize and enhance the productivity and design improvement advantages that BIM offers, the obstacles linked to interoperability need to be solved (Steel et al. 2012). Aside from interoperability, the lack of visualization standards (Douglas and Ferreira 2015), difficulties in using 4D BIM tools (Rolfsen and Merschbrock 2016) and the level of details (Boton et al. 2015) are perceived as the challenges towards 4D BIM implementation. Staub-French and Khanzode (2007) claim that establishing BIM guidelines can assist project organizations to eliminate the potential process-related, organizational and technical barriers that hamper the adoption of 3D and 4D BIM technologies. Consequently, the most common technical challenges to 4D BIM according to literature are: Interoperability, huge number of software, difficulties in using, and lack of standards.
Chapter 4: Findings

This chapter is structured based on the two objectives of the study. For each objective, the survey and interview findings are presented separately. It is worth noting that the survey data is presented first and the interview data is presented to supplement and validate the quantitative data.

4.1. Survey results

**Objective 1:** To find out the level of 4D BIM usage and the perceived qualities, advantages of 4D BIM over traditional construction planning approaches within Swedish construction companies.

The questionnaire was sent to a total of 40 companies, including 12 small, 22 medium sized and 6 large. In response 26 companies responded (5 small, 15 medium-sized and 6 large) with a total response rate of 65%.

Additionally, Fig. 1 shows the variety types of work undertaken by contractors of which the top four sections of work are buildings, roads/highways, bridges and harbors & ports.

Before coming to the findings of objective 1, some demographic questions were asked from participants in order to obtain a first access to the topic of BIM and the findings are as followed.

4.1.1. Demographic information

The participants were asked about their level of education and their experience in AEC industry. Concerning their education level, 88% of the participants are holding a Bachelors and/or Master degree (46% and 42% respectively), 8% hold a PhD and the remaining 4% have a high school degree. With regards to work experience, 62% of them had equally 5-10 and 10+ years of work experience, 23% with 3-5 years and the remaining 15% with 0-3 years’ experience.

In connection with the demographic information, questions regarding 3D and 4D BIM awareness as...
well as its usage were asked. All the respondents indicated that they are aware of both, 3D BIM and 4D BIM. Out of all, 77% used only 3D BIM; the remaining 23% were just aware but haven’t used it yet. When it comes to 4D BIM, half of the respondents indicated that they are not only aware of 4D BIM, but are also using it.

Several questions were asked to find the time gap between the first awareness and the first use. The earliest awareness of 3D BIM among respondents was the year 2005 and the latest 2014 with a mean of 2010. For 4D BIM the earliest awareness was 2008 and the latest 2016 with a mean value of 2013. Those who indicated they have used one or all of the BIM functions (3D, 4D and 5D) were further, asked when they have used it for the first time, the earliest adoption shows the year 2005 and the latest 2017 with a mean value of 2013. So, in average the time gap between their first awareness and first adoption is calculated to be 3 years (2013 minus 2010).

The following two questions were asked if the participants are currently using 4D BIM in their construction planning practices, or if they know someone else in their company doing it. The responses show that all large companies are currently using 4D BIM. While, in small companies it is the opposite. However, the figure depicts that almost 2/3 of medium-sized companies are using it. Nevertheless, there is a big difference between medium-sized and small companies (see Fig 2). Those who have not started using 4D BIM in their organizations yet, were further asked when they are planning to use it. In response 40% indicated they are “not sure” while 40% indicated they start using it within 1-3 years, the remaining 20% replied (3-5 years and 5-10 years equally).

Finally, participants were asked to rate their 3D and 4D BIM proficiency level. The answers show that the majority of the respondents have a satisfactory to advanced competency level in 3D BIM. Looking at 4D BIM, the majority has a poor to fair proficiency level. This reveals that the level of knowledge of 4D BIM is quite low among construction professionals. (Fig 3)

4.1.2. Relative advantages of 4D planning over conventional method

In the questionnaire the participants were asked to rate the relative advantages of 4D BIM functions and process over the traditional construction planning practices. The results show that most of the respondents agree with the relative advantages of 4D BIM functions and process over the traditional way of construction planning. Here, the function refers to the output of a construction planning process and process refers to the activities that construction planners do during planning. Table 1 shows the ranking of 4D BIM functions over the traditional construction planning methods. Based on the table, the visualization of the construction flow, simplifying understanding of the construction flow and logistics planning functions are mostly favored. In contrast, functions like “safety planning” and “work progress reporting” are both ranked the lowest, but still more preferred than the conventional
construction planning functions.

**Table 1 Relative advantages of 4D BIM functions over traditional construction planning**

1 (Much worse than traditional), 5 (Much better than traditional)

<table>
<thead>
<tr>
<th>Functions</th>
<th>Rank</th>
<th>Min.</th>
<th>Max.</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visualizing the construction flow</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>4.58</td>
</tr>
<tr>
<td>Simplifying understanding of the construction flow</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>4.19</td>
</tr>
<tr>
<td>Logistics planning (equipment and material flow to, within and from construction site)</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>4.12</td>
</tr>
<tr>
<td>Planning and coordinating working space</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>4.12</td>
</tr>
<tr>
<td>Planning construction methods (comparison of execution plans)</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>4.04</td>
</tr>
<tr>
<td>Site layout planning</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>3.96</td>
</tr>
<tr>
<td>Location-based planning</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>3.96</td>
</tr>
<tr>
<td>Validating and analysis of the time schedule</td>
<td>6</td>
<td>2</td>
<td>5</td>
<td>3.92</td>
</tr>
<tr>
<td>Design investigation</td>
<td>7</td>
<td>2</td>
<td>5</td>
<td>3.81</td>
</tr>
<tr>
<td>Work-progress reporting</td>
<td>8</td>
<td>1</td>
<td>5</td>
<td>3.69</td>
</tr>
<tr>
<td>Safety planning (scaffold; crane)</td>
<td>8</td>
<td>3</td>
<td>5</td>
<td>3.69</td>
</tr>
</tbody>
</table>

Likewise, respondents perceived the 4D planning processes such as “communicating project duration” and “communicating the construction plan” as better than done in the traditional way of working during construction planning. Whereas, processes such as “calculating activity duration” and “collecting information” are listed lowest in the ranking. Nevertheless, the value is still above average which means it is better than traditional. (see Table 2)

**Table 2 Relative advantages of 4D planning process over traditional construction planning**

1 = Much worse than traditional, 5 = Much better than traditional

<table>
<thead>
<tr>
<th>Functions</th>
<th>Rank</th>
<th>Min.</th>
<th>Max.</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communicating project duration</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>4.12</td>
</tr>
<tr>
<td>Communicating the construction plan</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>4.08</td>
</tr>
<tr>
<td>Sequencing the construction</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>4.04</td>
</tr>
<tr>
<td>Arranging the dependencies</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>4.00</td>
</tr>
<tr>
<td>Identifying activities</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>3.85</td>
</tr>
<tr>
<td>Calculating activity duration</td>
<td>6</td>
<td>2</td>
<td>5</td>
<td>3.81</td>
</tr>
<tr>
<td>Collecting information</td>
<td>7</td>
<td>2</td>
<td>5</td>
<td>3.73</td>
</tr>
</tbody>
</table>

4.1.3. **The perceived characteristics of 4D BIM innovation**

Several questions were asked to measure the compatibility of 4D BIM innovation within organizations, the complexity, trialability and finally if the positive impacts of using 4D BIM can be observed. The first question is linked to compatibility, followed by three questions to measure the complexity and the last two questions to check the trialability and observability attributes. The results show that averagely 4D BIM is not completely compatible nor is it easy
to see the positive impacts for both large and medium sized firms. With regards to complexity, 4D BIM is perceived to be more complicated by small and medium-sized contractors than by the large companies. Finally, the results for trialability characteristic of 4D BIM innovation show more positive responses than the average. That means there is a chance to try 4D BIM before using it. It is important to note that some companies have given higher frequency of agreement to each of these statements as can be seen under “Max” in table 3.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Small Med-sized</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 = Strongly disagree, 5 = Strongly Agree</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4D BIM is compatible with our current construction planning methods</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>It is difficult to learn 4D BIM methods</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>It is difficult for construction planners to understand 4D BIM methods</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>The training for 4D BIM learning is complicated</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>4D BIM methods need to be tried before using it for construction planning</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Upon using 4D BIM, it is easy to see the positive impacts on construction planning</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

Objective 2: To explore the possible incentives, limitations and driving forces that influences 4D BIM use within Swedish medium-sized and large construction companies.

4.1.4. 4D BIM use

Those respondents who answered that they use 4D BIM themselves or know someone in their organization who is using 4D BIM were further asked how often they use each of 4D BIM functions. The following table illustrates the functions such as “visualizing the construction flow” and “facilitating the understanding of construction flow” as the two most used functions. Whereas, functions such as “logistics planning” and “comparison of execution plans” were indicated as less-used functions by participants. Again, some companies in the sample, has a higher frequency of use for each of these functions as listed under “Max” in table 4.
Table 4. The extent to which 4D BIM functions are used
1 = Never, 2 = Rarely, 3 = Sometimes. 4 = Often and 5 = Always

<table>
<thead>
<tr>
<th>Functions</th>
<th>Rank</th>
<th>Min</th>
<th>Max.</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simplifying understanding of the construction flow</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>3.43</td>
</tr>
<tr>
<td>Visualizing the construction flow</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>3.36</td>
</tr>
<tr>
<td>Site layout planning (locating)</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>3.00</td>
</tr>
<tr>
<td>Planning and coordinating working space</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>3.00</td>
</tr>
<tr>
<td>Location-based planning</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>2.93</td>
</tr>
<tr>
<td>Validating and analysis of the time schedule</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>2.86</td>
</tr>
<tr>
<td>Design investigation</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>2.86</td>
</tr>
<tr>
<td>Safety planning (scaffold; crane)</td>
<td>6</td>
<td>1</td>
<td>5</td>
<td>2.64</td>
</tr>
<tr>
<td>Work-progress reporting</td>
<td>6</td>
<td>1</td>
<td>5</td>
<td>2.64</td>
</tr>
<tr>
<td>Planning construction approaches (comparison of execution plans)</td>
<td>6</td>
<td>1</td>
<td>4</td>
<td>2.64</td>
</tr>
<tr>
<td>Logistics planning (resources flow to, within and from construction site)</td>
<td>7</td>
<td>1</td>
<td>4</td>
<td>2.57</td>
</tr>
</tbody>
</table>

4.1.5. Barriers to 4D BIM

Next, the participants were asked about the barriers which hinder 4D BIM implementation in their organizations. According to table 5, the top 2 ranked barriers are linked to the client “lack of demand from the client” and “lack of clients’ knowledge” on 4D BIM”. However, the third highest ranked barrier is related to internal organization as “lack of 4D BIM knowledge within internal organization”. Surprisingly, all the top five ranked barriers are non-technical, followed by the “lack of standards” which is a technical barrier.

Table 5. Barriers to adopt 4D BIM within Swedish construction companies
1 = Strongly disagree, 2 = Disagree, 3 = Neutral. 4 = Agree, 5 = Strongly agree

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Rank</th>
<th>Min</th>
<th>Max.</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of demand from the client side to use 4D BIM</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>3.77</td>
</tr>
<tr>
<td>Lack of client knowledge about 4D BIM</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>3.73</td>
</tr>
<tr>
<td>Lack of 4D BIM knowledge within internal workforce</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>3.65</td>
</tr>
<tr>
<td>Lack of 4D BIM expertise in the market</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>3.50</td>
</tr>
<tr>
<td>Our partners (other firms) do not use 4D BIM</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>3.46</td>
</tr>
<tr>
<td>Lack of standards for 4D BIM</td>
<td>6</td>
<td>1</td>
<td>5</td>
<td>3.38</td>
</tr>
<tr>
<td>Traditional project delivery methods/contract</td>
<td>7</td>
<td>1</td>
<td>5</td>
<td>3.35</td>
</tr>
<tr>
<td>Resistance to change from traditional planning practices to 4D BIM</td>
<td>7</td>
<td>1</td>
<td>5</td>
<td>3.35</td>
</tr>
<tr>
<td>The lengthier process of 4D BIM creation</td>
<td>8</td>
<td>1</td>
<td>5</td>
<td>3.23</td>
</tr>
<tr>
<td>Lack of internal demand to use 4D BIM</td>
<td>8</td>
<td>1</td>
<td>5</td>
<td>3.23</td>
</tr>
<tr>
<td>The complicated training process of 4D BIM</td>
<td>9</td>
<td>1</td>
<td>5</td>
<td>3.19</td>
</tr>
<tr>
<td>Problems with exchanging data between software</td>
<td>10</td>
<td>1</td>
<td>5</td>
<td>3.15</td>
</tr>
<tr>
<td>High costs of training</td>
<td>11</td>
<td>1</td>
<td>5</td>
<td>3.12</td>
</tr>
<tr>
<td>Difficulty in measuring the advantages of 4D BIM</td>
<td>11</td>
<td>1</td>
<td>5</td>
<td>3.12</td>
</tr>
</tbody>
</table>
It is noteworthy that some companies in response to an open-ended question about “other constraints” have also demonstrated some technical and non-technical barriers in terms of standards or a common language, incompatibility, time and cost.

“Need better standards for making BIM models and to make a 4D BIM out of it. Also lack of time for employees to search and learn new things”

“...the problem is that the project is seldomly defined by that point and the design work is undergoing as we are building. Keeping a 4D/5D BIM updated is really hard and time consuming. Just getting the progress data from the supervisors is hard enough as it is. There is no economical motive to add those extra resources to the project.”

“The quality of the various disciplines models”

4.1.6. Incentives for 4D BIM

With regards to the incentives for 4D BIM implementation, most of respondents have chosen the 4D BIM innovation as the great reason to follow technical growth and to gain competitive advantages. That is why, 4D BIM has also a strategic importance to the companies, as ranked number 3. Notably, the lack of demand from the clients and the lack of 4D BIM use by other firms as main constraints to 4D BIM adoption were further confirmed here, but ranked the lowest with mean values of 1.92 and 2.31 respectively (see Table 6).

<table>
<thead>
<tr>
<th>Table 6. Incentives to adopt 4D BIM within Swedish construction companies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Incentives</strong></td>
</tr>
<tr>
<td>By using 4D BIM we can achieve technical development</td>
</tr>
<tr>
<td>We know that by using 4D BIM we can obtain competitive advantages</td>
</tr>
<tr>
<td>4D BIM technology has a strategic importance to our company</td>
</tr>
<tr>
<td>4D BIM helps to expedite the decision making process</td>
</tr>
<tr>
<td>4D BIM cut the risks by reducing onsite conflicts and change orders</td>
</tr>
<tr>
<td>We get good support from consultants to use 4D BIM in our projects</td>
</tr>
<tr>
<td>We have proper internal expertise to implement 4D BIM</td>
</tr>
<tr>
<td>It is straightforward and easy to adopt and use 4D BIM</td>
</tr>
</tbody>
</table>
4.1.7. Solution/Driving forces

Lastly, the respondents were asked, as to what extent they consider the following solutions or drivers as strong enough to overcome the barriers that can enhance the widespread adoption of 4D BIM. In response, 4D BIM standardization was selected as first and foremost solution among all. In addition, understanding the business value of 4D BIM or its clear benefits was ranked number 2. It confirms that the lack of tangible benefits of 4D BIM is also a significant barrier towards its adoption. In sum, the respondents give above average rating to all the solutions indicated below (see Table 6).

<table>
<thead>
<tr>
<th>Solutions/Drivers</th>
<th>Rank</th>
<th>Min.</th>
<th>Max.</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>4D BIM become a standard in all projects</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>3.92</td>
<td>.891</td>
</tr>
<tr>
<td>We realized clear benefits of 4D BIM</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>3.88</td>
<td>.816</td>
</tr>
<tr>
<td>Good support from software vendors (e.g. training, trial ver. low price)</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>3.58</td>
<td>.758</td>
</tr>
<tr>
<td>Our partners start using 4D BIM</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>3.54</td>
<td>.948</td>
</tr>
<tr>
<td>Public sector mandate 4D BIM</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>3.50</td>
<td>1.208</td>
</tr>
<tr>
<td>The internal authority level required 4D BIM</td>
<td>6</td>
<td>1</td>
<td>5</td>
<td>3.27</td>
<td>1.079</td>
</tr>
<tr>
<td>Lower costs for software and hardware</td>
<td>7</td>
<td>1</td>
<td>4</td>
<td>3.12</td>
<td>.909</td>
</tr>
</tbody>
</table>

4.1.8. The summary of survey findings

The level of awareness of 4D BIM is high among all types of construction companies in Sweden (small, medium-sized and large). However the level of 4D BIM proficiency was lower than 3D BIM among construction professionals participated in this survey. This reveals there seems to be lack of knowledge among internal workforce as 4D BIM is still very new in most of the companies.

Interestingly, smaller companies found 4D BIM more complex and less compatible with their current construction planning practices than large companies. When it comes to trialibility, the majority agrees that 4D BIM technology should be experimented before using it. As it is not easy to see the positive impacts of using 4D BIM within their construction planning practices, it means it is hard to measure 4D BIM benefits.

Most of the respondents preferred 4D BIM over traditional construction planning. Thereby, visualizing the construction flows, simplifying the understanding of a construction process,
and logistics planning are highest ranked among the functions of interest by the participants. With regards to the 4D BIM usage, all large companies have started to use 4D BIM, while its use is limited in medium sized companies, and small companies have not started using it. Those who use it have again chosen the visualization and the understanding of the construction flow as the most frequently used functions, while comparison of construction methods and logistics planning are the less frequent used functions.

The top five barriers linked to 4D BIM adoption were found to be non-technical, namely lack of clients’ demand and knowledge, lack of internal workforce knowledge and 4D BIM as the less-common tool among partners. While the “lack of standard” was the first of the technical barriers mentioned, it is ranked number 6 in the table. The most prominent incentives in using 4D BIM were their technical growth and that it can provide them with competitive advantages. Finally, standardization of 4D BIM was selected as the best solution/driver towards 4D BIM adoption which was followed by “realizing the business value/clear benefits of 4D BIM”.

4.2. Interview results

The purpose of interviews was to validate the quantitative data and to go deeper into the research topic. The interviews took place within a period of two weeks with representatives of seven companies, three medium-sized and four large companies. The interview questions were formulated in a way to cover the objectives of this study.

Table 8: Details of interview

<table>
<thead>
<tr>
<th>No.</th>
<th>Participant</th>
<th>Position</th>
<th>Interview Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Large Company (LC1)</td>
<td>Model-based approach Strategist</td>
<td>42 minutes</td>
</tr>
<tr>
<td>2</td>
<td>Large Company (LC2)</td>
<td>Head of BIM Department</td>
<td>55 Minutes</td>
</tr>
<tr>
<td>3</td>
<td>Large Company (LC3)</td>
<td>Design Manager and BIM Responsible</td>
<td>42 minutes</td>
</tr>
<tr>
<td>4</td>
<td>Large Company (LC4)</td>
<td>VDC Specialist</td>
<td>43 minutes</td>
</tr>
<tr>
<td>5</td>
<td>Medium-sized Company (MC1)</td>
<td>Senior Process Manager</td>
<td>37 minutes</td>
</tr>
<tr>
<td>6</td>
<td>Medium-sized Company (MC2)</td>
<td>BIM Strategist</td>
<td>53 minutes</td>
</tr>
<tr>
<td>7</td>
<td>Medium-sized Company (MC3)</td>
<td>Project Engineer</td>
<td>47 minutes</td>
</tr>
</tbody>
</table>

All the interviews were recorded and transcribed to ensure the efficiency and to monitor the quality of the responses. Furthermore, the coding of responses method was utilized and important information from the participants’ answers were derived and listed under several categories. The similarities and differences in the views of large and smaller contractors were further analyzed. The following tables contain the grouping of findings and quotes from interviewees related to each subject of this study.
Objective 1: To find out the level of 4D BIM usage and the perceived qualities and advantages of 4D BIM over traditional construction planning approaches within Swedish construction companies.

4D BIM versus traditional construction planning

In general, most of the interviewees agreed on 4D BIM as the better tool for communication as well as collaboration and as an efficient tool for construction planning. Participants have mostly emphasized on the visualization capabilities of 4D BIM that can facilitate a better understanding of the construction flow and at the same time for logistics planning. However, those respondents who use 4D BIM practically on a daily basis have expressed their concern about software that does not meet their needs e.g. problems in visualizing the internal activities like painting. They conditionally agreed on 4D BIM as a better tool if the level of information in the schedule and the level of detail in the model is higher, for example integrating day to day activities in the 3D model and use it for weekly look ahead schedules on the production site. With regards to efficiency (regarding time and costs), all contractors almost agree on 4D BIM being efficient. Although some of them found 4D BIM more time and cost consuming in the planning phase, they believe that it will pay-off in the production phase.

4D BIM use

In this section interviewees were asked about their decision making process, their current status whether they use 4D BIM and if they have strategies for it in the future.

Current status: All of the respondents from medium-sized and large companies were aware of 4D BIM and have already started using it. Large companies seem to lead the way in the adoption of 4D BIM since they have many ongoing projects with 4D simulation. Nevertheless, 4D BIM is not fully adopted in all of their projects. The medium-sized companies have proceeded in a similar way having some ongoing pilot projects with 4D simulations. According to some of them, the client’s requirement or project characteristics e.g. complexity, type and size are the factors influencing their decisions to use it or not. Some of the larger companies have similar thoughts regarding the client’s requirements. Those companies which are developing and building for themselves are not affected by the clients’ requirement at all. They usually have internal demand to
implement smarter ways for construction effectiveness.

Decision: All of the interviewees mentioned that the decision is taken top-down whether to fully adopt a new technology or not. But the initial idea is raised bottom-up. For example, the VDC department has to test the new technology like 4D BIM in several pilot projects and prove the benefits to the top authority level before they decide on it. In this regard, the regional offices or onsite project teams are decentralized or have freedom in deciding to use smart tools and try new ways for effective construction planning. Then again the decision-making process according to most of the respondents is lengthy which can be perceived as a barrier that slows down the adoption process. Interestingly, according to LC4, the decision-making process in widespread of 4D BIM in medium-sized companies should be faster due to a smaller size of organization. However, for big companies it is lengthy due to the long chain of command.

Functions: Among 4D BIM functions, visualization of the construction flow and to communicate within the production phase was the most common function among all contractors. Though, some large companies use it for logistics and safety planning, too. While medium-sized companies limit their use to the basic functions only.

Strategy: It was very interesting that everyone perceived 4D BIM as the future of construction planning with strategies in hand to change the planning process within the horizon of 3 to 5 years. However, as stated by most of the interviewees, the transformation process is not something to be done “overnight” it needs time and investment.

Objective 2: To explore the possible incentives, limitations and driving forces that influences 4D BIM use within Swedish construction companies.

<table>
<thead>
<tr>
<th>Incentives/driving forces</th>
<th>Quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>The words “internally driven” and “client’s requirements” were heard repeatedly during the interviews. Thus, the incentives for using 4D BIM are divided into two categories: Internal and External incentives;</td>
<td>“because we want to do our construction processes better” MC1</td>
</tr>
<tr>
<td>“I don’t really see the reason why not to do it, once you start having the models from the beginning of the project” MC2</td>
<td></td>
</tr>
</tbody>
</table>
**Internal:** It was unexpected that 4D BIM use would be mostly driven internally. Most of the respondents mentioned that inefficiency in the construction phase, modernization innovation, profiling, facilitating better communication and coordination and finally attracting future employees are among those incentivizing forces which lead their organizations to adopt new ways of working like using 4D BIM. LC1’s quote “it is much more fun and that way we can attract more employees” underlines that large companies appreciate using 4D BIM and are optimistic about absorbing future generations to the construction industry.

**External:** Although, internal driving forces play a key role in the adoption of 4D BIM, some respondents from medium sized contractors were also persisting on client’s demand as a driver that pushed them to start using it, as quoted by MC3 “the requirements we got from the client already pushed us a little bit”. Moreover, competition among contractors to attract more clients in getting more contracts and to maintain their strategic position in the market were additional interesting points being raised by all companies (see quotes).

### Barriers to implement 4D BIM

<table>
<thead>
<tr>
<th>Technical: The technical barriers group is further categorized into three subgroups a) Standards b) Complexity c) Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>a: Standards: The lack of national standards was stressed among technical barriers. The inexistence of a common BIM language in Sweden makes it harder for companies to decide on to what extent they use it. This in turn led people to have different perceptions and expectations from BIM, 4D BIM and 5D BIM. Especially, when it comes to the level of detail/information. Despite standards from U.K. and the U.S. like AIA (American Institute of Architects), which are available and</td>
</tr>
</tbody>
</table>

| “We don’t have our standard”<sup>LC3</sup> |
| “there is no standard”<sup>MC1</sup> |
| “we don’t have this common BIM manual”<sup>LC2</sup> |
| “everyone thinks of BIM differently and different expectations”<sup>LC2</sup> |
| “we are lacking decision or regulation or requirements from the government and I compare with both Norway and”<sup>LC4</sup> |
cover many aspects of 4D BIM, LC4 hinted at an interesting point: "the barrier is not that there are no standards but it is that we are not using it". This can be linked again to some non-technical issues like lack of knowledge.

b: Complexity: With regards to the 4D BIM process, complexity was one of the controversial topics; among all, five respondents (from large and medium-sized companies) found 4D BIM as complex. The complexity according to a few of them is usually related to employees’ age band and their interests. For example, it will be difficult and complicated for a person with 30+ year of experience in traditional construction planning to learn or accept 4D BIM immediately stated by LC3. Since every new innovation or technology offers trial versions, the interviewees were also asked about trialability of 4D BIM technologies. Trialability refers to the chance to try a technology before implementation. In response, it was made clear that those companies who already started using 4D BIM had the chance to try it. The respondent from LC3 however indicated that they are still in the process of trying it before completely changing their planning process to 4D.

C: Software: Furthermore, respondents from both company sizes stated their concerns about software issues that either does not meet their needs or the formats are not interoperable.

Non-technical

A group of non-technical barriers has also been highlighted by interviewees. Data shows that non-technical barriers are stressed even more than the technical barriers. By merging the responses from both medium-sized and large companies, the following four sub-categories of non-technical barriers emerged that hamper the 4D BIM adoption process in common.

   a) organizational challenges;
   b) client;
   c) unclear benefits;
   d) investment

a: Organization:

"right from get to go, it does not work with your organization " MC1
Organizational problems like employees resistance to change, incompatibility and the lack of internal knowledge are the primary organizational issues stated by most of the interviewees. Since all the interviewed companies specified that they are in the beginning phase of 4D BIM adoption, particularly the employee’s resistance to change was considered as the biggest challenge for them in the transformation process. The
organizational culture associated with traditional thinking led to 4D BIM being incompatible with the organizational culture. According to some of them, the lack of knowledge at the management level is perceived as another obstacle that lead the companies’ top level to continue with their traditional practices.

b: Client: Lack of client’s demand and their limited knowledge about 4D BIM were the highest ranked barriers among the quantitative results. Whereas, from the interview data it appears that they are more suffering from the organizational issues than lack of client’s requirement. However, the client’s demand was still perceived as one of the significant constraints among a few companies. For example: for LC1 and LC3, the lack of client’s demand was not a very big issue since their clients are the buyers of apartments/houses. Unlikely, for medium-sized companies who get general contracts from public or private sectors, the lack of client’s demand and sometimes unclear requirements were perceived as the primary barriers. Unexpectedly, respondents ranked “Our partners (other firms) do not use 4D BIM” as number5. Thereby, other firms refer to other contractors who are working in the same environment.

c: Unclear benefits: One of the captivating findings was that no one from the interviewees has measured the efficiency of 4D BIM in monetary values. It is worth noting that most of the respondents demonstrated that the impacts of using 4D BIM are visible for them but when it comes to figures, it is hard to measure. However, a few companies see it as a barrier towards the widespread adoption of 4D BIM.

d: Investment: Despite the ranking in terms of time and cost was significantly low in the quantitative data, in qualitative data, the words “time” and “resources” were consistently mentioned by respondents. The time was frequently linked to the organizational change process. Likewise, the investment required to modernize the IT infrastructure, to recruit new roles, to educate or capacitate the existing organization. These factors were reflected as substantial challenges on their journeys towards BIM/4D BIM implementation.
To re-verify the barriers and incentives brought up by respondents and to find out which solutions are more important for them, questions were asked about what are the best solutions to overcome the barriers that they are facing and to enhance the widespread adoption of 4D BIM.

In response, the following solutions/drivers were chosen collectively by large and medium-sized companies.

<table>
<thead>
<tr>
<th>Solutions/Drivers</th>
<th>Quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Developing local standards</td>
<td>“I believe once these requirements become more solid, the speed of evolving this subject will be high” MC2</td>
</tr>
<tr>
<td>b) Mandate BIM</td>
<td>“If public sector put requirements we will of course fulfill it” LC2</td>
</tr>
<tr>
<td>c) More research to identify 4D BIM benefits/business value</td>
<td>“Once we get to the point when the client requires it for all the jobs then the acceptance will drive very quick” MC2</td>
</tr>
<tr>
<td>d) Software</td>
<td>“Doesn’t matter for us [to mandate 4D BIM]” LC1</td>
</tr>
<tr>
<td></td>
<td>“Mandating BIM by public sector is also very important” LC2</td>
</tr>
<tr>
<td></td>
<td>“Absolutely, [mandating BIM], we go after our clients, if they want us, we will get that” LC4</td>
</tr>
<tr>
<td></td>
<td>“I am sure if the client starts to come forward with requirements, we will have really quick implementation” LC2</td>
</tr>
<tr>
<td>a: Local standards: There was a significant consensus among respondents, demanding local BIM standards or a common language to facilitate the level of detail or level of information (LOD/LOI) between stakeholder. That way everyone holds similar definitions and expectations of BIM/4D BIM.</td>
<td></td>
</tr>
<tr>
<td>b: BIM mandate ”Once we get to the point when the client requires it for all the jobs then the acceptance will drive very quick” MC2</td>
<td></td>
</tr>
<tr>
<td>Mandating BIM by most of the respondents was also among top solutions that can help to promote 4D BIM implementation. This also means that the public sector has stronger steering power that can lead contractors to adopt a new technology. For example, once the client requires it in the contract, the contractors will immediately take actions to fulfill the requirements, and this in turn contributes to expedite the change process.</td>
<td></td>
</tr>
<tr>
<td>d: Research: One of the fascinating findings was that for adopting an innovation like 4D BIM, the benefits or the business value should be clear enough so that the top management is convinced to decide upon the adoption of 4D BIM. According to some of the interviewees, more researches are needed to uncover the real business value or tangible advantages of 4D BIM.</td>
<td>“The first thing you have to do before starting implementing BIM is doing a lot of research” MC1</td>
</tr>
<tr>
<td></td>
<td>“See, how other companies using, do not get closed with Swedish type of view” MC1</td>
</tr>
<tr>
<td></td>
<td>“It is hard to see the possibilities that maybe one solid case study first like we did it here, these are the effects it is black and white then when u really had that case study I think it’s going to spread very quickly” LC3</td>
</tr>
<tr>
<td></td>
<td>“We have to try and make more pilot projects evaluating and continue developing the new way of working with the 4D BIM” LC2</td>
</tr>
</tbody>
</table>
**Software:** As software was found to be one of the main technical barriers for the practical users of 4D BIM planning, support from software vendors in training, increase of the period for trial versions, lowering the costs and developing software to meet their needs, in particular to visualize the internal activities were among solutions that could offer more facilitation to the users and in turn help to widespread the adoption of 4D BIM.

"Software vendors support" MC1
"They are not going to do that [lower the software prices], if they do. Yes it can be a solution" MC3
"Cost is always an issue, cost reduction is also a solution" LC3
"The software need to work much better and developing tools in a better way" LC3
"it [software] needs to be so simple, as easier as possible" LC3
Chapter 5: Discussion

A general review to the findings show high similarities among statistical and interview findings exist. This reflects that the finding for quantitative data is valid to a large extent. However, in this chapter the differences in thoughts and the key findings to the objectives of this study are further discussed and linked to the literature.

The findings show that almost all contractors in Sweden are aware of 4D BIM concept. However, the proficiency level in 4D BIM seems to be lower compared to 3D BIM. Additionally, in average the years of first awareness and the first use were found to be 2010 and 2013 respectively. This reveals that 4D BIM is a new technology and has not yet matured. It normally takes around three years until individuals in an organization replace their traditional way of construction planning with 4D BIM. This is further confirmed in response to the question asked about their strategies in fully adopting 4D BIM, where 50% of individuals in the survey indicated they will fully adopt 4D BIM within the horizon of 1-5 years and in the interviews the interviewees stated within 3-5 years. Moreover, all of the large companies have started using 4D BIM in their construction planning practices but as the company size gets smaller, the 4D BIM use become limited as well. Therefore, it is believed that the poor proficiency level is due to the lack of experience, and the lack of experience can be explained by the limited access of smaller companies to BIM projects. Thus, a link between literature and application can be seen. “Smaller companies tend to suffer the most since their engagement in BIM projects is less and therefore they are less experienced” (Ghaffarianhoseini et al. 2017).

Interestingly, almost everyone surveyed and interviewed confirmed that 4D BIM was relatively better than the traditional construction planning practices, especially when it comes to visualization and communication capabilities. But the interviews further uncovered the difficulty in visualizing internal activities e.g. painting, piping in 4D BIM. Additionally, some interviewees added that it would be better “if” it is used in an advanced way with higher level of information. But overall, the 4D BIM functions and processes are perceived better than conventional functions and processes, if it is used in the right way with a sufficient level of information. Therefore, a consistency appears to exist between (Rogers 2003) innovation diffusion theory and the actual application as an innovation can be rapidly diffused if individuals perceive it with having a higher relative advantage (Rogers 2003).

A deeper scrutiny of the use of 4D BIM shows that despite some companies using 4D BIM but they are still in the initial phase and have deployed only few functions of 4D BIM. The interviewees confirmed that visualization, understanding of the construction flow and coordinating working space were the most commonly used functions compared to other functions. Since visualization of the construction flow is one of the top ranked functions and this leads to a better understanding therefore it can be considered as a proxy of communication and coordination and thus one of the advantages of 4D BIM (Hartmann and Vossebeld 2013; Murguia and Brioso 2017).
“For single family houses 4D BIM is used more logistical, not for time planning”

“For we get renovation of the building we don’t find it useful”

“depending on the complexity of the project it could be a good idea to have it”

Furthermore, based on interview data complexity, size and type of a project determine if BIM and especially if 4D BIM is used. In this regard, few large companies have stated they have specific guidelines to decide upon using BIM in relation to the size of projects in terms of budget. But, smaller companies will not start working with BIM as they work mainly on smaller projects such as single-family houses or renovation. As the clients of single-family houses are the homeowners, people who have no knowledge of BIM, they do not demand for the use of BIM. Consequently, as Ghaffarianhoseini et al. (2017) stated, the smaller companies have no incentives to start working with BIM as it is not requested by their clients and so far, only means time and money to train their employees for something they cannot use because no one will pay them for it. In case of joint ventures with other construction companies, especially with large companies, they are not yet expected to deliver 4D BIM data. As stated by one of the interviewer of a large company, they expect their subcontractors to work with 3D BIM, nevertheless showing them what 4D BIM can do and how it will be included in the project. That way, they will be encouraged to start working with it sooner or later, particularly to remain competitive and of interest for future joint ventures. Therefore, it is believed that, implementing 4D BIM in smaller and less-complex projects would be an extra cost, due to its limited budget and restraint resources. Additionally, the client might either not provide a 3D model or not require 4D BIM in the contract, in order to persuade the contractor to use 4D BIM in projects with these characteristics.

Surprisingly, all of the barriers stated in literature study were also addressed by interviewees and survey respondents. This further shows that these constraints are severe impedance towards the implementation process of 4D BIM. Understanding the challenges, helps develop strategies and solutions to overcome these challenges (Kassem et al. 2012). The findings show that the adoption process of 4D BIM in Sweden is more prone to non-technical problems than technical barriers. This is similar to UK construction industry (Kassem et al. 2012). The most common technical barriers addressed by interviewees was found to be the lack of clear national standards like U.K. and Norway; software issues that do not meet users’ needs especially for internal activities and the process complexity. Since 4D BIM is not standardized yet and is not commonly used among Swedish contractors. This has affected the adoption process. Though, BIM Alliance Sweden is an entity that promotes BIM standardization. However, when it comes to 4D BIM, as stated by respondents there are different expectations regarding Level of Details and Level of Information LOD/LOI of 4D BIM among contractors which means there is lack of normative pressure (Cao et al. 2014) on contractors to adopt 4D BIM. On the other hand the respondents raised a wide range of non-technical (organization, client, unclear benefits, investment and external) factors which were stressed even more as critical obstacles towards 4D BIM implementation. Incompatibility of 4D BIM innovation within an organization was elicited widely, this was due to lack of knowledge and experience within organizations because experience creates a righteous path that can help to employ the required technics, so without employing those technics, it is
impossible for people to improve their experience or knowledge. Employee’s resistance to change is another organizational barrier as stated by most of the interviewees:

“4D and 5D BIM is the wave of the new generation” MC2
“I give courses in 4D BIM, so it depends on generation, our generation learns very fast” LC3
“…a big part of compatibility issue is changing our views on scheduling and planning, and combined that with generation of our employees that don’t like technology or scared of technology” LC4

Therefore, a link exists between people and technology use (Kunz and Fischer 2011). Furthermore, adopting BIM requires a change. But, adopting and accepting new technology is difficult for those who have gained decades of experience using traditional methods or not comfortable with this change (Arayici et al. 2009). However, it is believed that the new generation is keen and accepts technology rapidly.

Additionally, there was a consensus among interviewed and surveyed individuals that the lack of the client’s knowledge and demand as well as the difficulty to measure the benefits versus costs (business value) are the major constraints for the adoption of 4D BIM. It is analyzed that when the clients lack knowledge about 4D BIM, there is no motive for them to ask for it in the contracts. Furthermore, if the benefits 4D BIM has to offer cannot be examined in monetary terms, it could be difficult for companies to invest in something that has unclear benefits and requires huge start-up costs. Thus, it is claimed that the lack of client’s demand and the unobservable benefits of 4D BIM are the main non-technical barriers for 4D BIM adoption (Kassem et al. 2012). It was unexpected that contractors are also influenced by the action of each other in terms of using a technology. Table 5 (see section 4.1.5) shows that one of the barriers, which limit the use of 4D BIM so far, is because other firms or partners do not use it. This is further verified looking at the same variable in table 7 (see section 4.1.7) ranking number 4 “when our partners start using 4D BIM” is perceived as a driver for companies to use 4D BIM. Consequently, it can be concluded that 4D BIM adoption is widely influenced by mimetic pressure as well (Cao et al. 2014). In addition, the complexity and less observable attributes of 4D BIM innovation made the innovation diffusion process weaker. An innovation which is less complex and more observable can be diffused rapidly (Rogers 2003). One of the respondents of the medium-sized contractors stated that they consider the lack of client’s demand as the most important barrier in 4D BIM adoptions. Once a client requires the use of 4D BIM, it will be easy to enable the teams and thus expedite the change process which will in turn result in quicker adoption. Thus, a coercive pressure (Cao et al. 2014) from the public clients, who are known as change makers (Vass and Gustavsson 2017) is significantly essential in order to expedite the adoption process.

Moreover, the cost for hardware, software and training is not a big issue for most of the companies according to table 5 (see section 4.1.5), but the interview data indicates that some companies find the costs for IT infrastructure and the time needed for the transformation process as challenging. This proves to be true as smaller or medium-sized companies suffer more from lack of resources in order to invest in modern IT tools (Bryde et al. 2013). Especially if at the same time the client does not demand or pay for it.
With regards to incentives/driving forces, it was remarkable that the technical growth and the competitive advantages were perceived as the strongest incentives for companies of all sizes as shown in table 6 (see section 4.1.6) and in the interview findings (see section 4.2). It can be claimed that larger companies are also under competition or mimetic pressure (Cao et al. 2014) from inside and outside of Sweden and that is why they try to adopt innovations like 4D BIM immediately to maintain their strategic positions. Whereas, the medium-sized companies are influenced mostly by client’s requirements and wait until a client asks them to use it. It is worth noting that some medium-sized companies are still competing to be ahead in terms of technology as well. In addition, placing “4D BIM was a clear demand from the client” in the lowest rankings further confirms the lack of client’s demand as a barrier to 4D BIM adoption (Kassem et al. 2012).

Finally, the 4D BIM standardization was perceived as the first and foremost solution to overcome the barriers and for a rapid adoption. This indicates that the Swedish construction industry is willing to accept and to adopt new innovations like 4D BIM. Moreover, 4D BIM mandate was also considered the best solution that can expedite the adoption process. Once 4D BIM is mandated, the companies will change their ways of working to what the client wants and what is common in the industry. Therefore, the public sector can play a vital role in adopting a technology within construction (Vass and Gustavsson 2017). From the technical point of view, software vendors have to develop software that matches with the user’s needs and increases the awareness sessions so that the level of knowledge increases and thus, the gap of lack of knowledge and of experience is being filled.

Reflection on theories

The Diffusion of Innovation Theory asserts that “Innovations that are perceived by individuals as having greater relative advantage, compatibility, trialability, and observability and less complexity will be adopted more rapidly than other innovations” (Rogers 2003). This study found out that contractors perceive 4D BIM as having greater relative advantages with great trialability capabilities. However, the complicated process of 4D BIM, incompatibility with the current organization and construction planning practices as well as the difficulty of observing the benefits of 4D BIM have weakened the 4D BIM innovation diffusion process. Additionally, the three isomorphic institutional pressures (DiMaggio and Powell 1983; Cao et al. 2014) also influence the 4D BIM adoption process. Based on the findings, the “lack of client’s demand” as a barrier and a “BIM mandate” as a solution indicates that clients as a powerful entity can put coercive pressure on contractors and thus, push the adoption process forward. Coercive pressure implies, when an organization becomes under pressure of another powerful organization they are affiliated with (Co et al. 2014). Such a coercive pressure is the dependency of contractors on public sector or other powerful firms who use 4D BIM. Additionally, contractors are also influenced by mimetic pressure. As, “our partners or other firms not using 4D BIM as barrier and; when our partners start using 4D BIM as a solution in tables 5 and 7 (section 4.1.5 and 4.1.7) respectively reveals that an uncertain situation exists in using 4D BIM innovation. Hence, contractors model themselves based on each other in the market. Finally, due to the lack of standards as a barrier, as well as for a call for national
“BIM standards” as a solution indicates that, in order to facilitate the 4D BIM adoption process, a normative pressure is needed. The normative pressure refers to professional bodies within a specific field developing shared norms for an organization. For example: the BIM Alliance Sweden as an entity who strives for BIM standardization.

Reflection on sustainability

As stated earlier, 3% of greenhouse emissions in Sweden are generated from the construction industry which is mainly coming from transportation and construction equipment (SCB 2018). Besides, 37% of construction material in the U.S. turns into waste (Economist Magazine, 2002 cited by Tommasi and Achille 2017). It was interesting to see that companies perceived 4D BIM as resource and time saver and thus implemented sustainable practices into their construction planning practices. For example, MC3 pointed out that 4D BIM logistics planning can help them to minimize transportation, reduce waste and to deliver the right material to the right place at the right time. For this reason, they are building a joint logistics center that helps companies to purchase and transport materials from the same place. Additionally, replacing digital tools over blueprints has also reduced the waste to an extent that makes the process more sustainable. Consequently, 4D BIM as a tool for communicating and coordinating the construction planning process helps to enhance productivity (Johnson and Laepple 2003) and save resources (Rolfsen and Merschbrock 2016). This in turn contributes to achieve sustainability goals.
Chapter 6: Conclusion

This study aimed to find the possible incentives for and barriers to 4D BIM adoption within Swedish construction companies. The research employed literature study, online survey and interview data collection methodology. Both, a questionnaire based survey and interviews were taken place to collect quantitative and qualitative data respectively and to answer the research question “what are the incentives for and barriers to 4D BIM adoption within Swedish construction companies?” and the sub-questions

- How much are the construction professionals familiar with 4D BIM?
- How do construction professionals perceive 4D BIM over traditional methods?
- To what extent are they using it?
- Why have they decided to use it (incentives)? Or why have they not (barriers)?
- What are the best solutions to overcome the barriers and promote 4D BIM?

through two specific objectives of this thesis:

- to find the extent of 4D BIM use within Swedish construction companies and their perception about relative advantages of 4D BIM; and
- to explore the possible incentives, limitations and driving forces that influence 4D BIM use;

The literature study aimed to establish a theoretical framework and explore earlier studies in the subject area which have been the basis for the survey and the interview questions. The sample of respondents for quantitative data consisted of 26 companies (5 small, 15 medium-sized and 6 large companies) and the results were presented quantitatively. The qualitative data was retrieved from 7 interviews (3 medium-sized and 4 large companies) and the coding of responses was used to categorize the findings for further analysis.

The results indicated that:

- The level of awareness of 4D BIM is high among Swedish contractors. Whereas, the lack of experiences and skills in 4D BIM is remarkable.
- Overall, 4D BIM is perceived as relatively better than traditional construction planning methods. Large companies are found as the first adopters of 4D BIM, but the use is limited within small and medium-sized companies. Nevertheless, 4D BIM is still not mature within the industry and all firms are in the beginning phase of the adoption which means they only apply the basic functions of 4D BIM e.g. visualization, communicating the construction flow and to some extent the logistics planning.
- Two main common categories of barriers to 4D BIM adoption were identified, namely: Non-technical and Technical. The Non-technical barriers constituted five subgroups as organization change, lack of client’s demand, unclear benefits, investment and some external factors. Just a few respondents within the interview
elaborated about technical obstacles to 4D BIM adoption in terms of functionality and usability. Each of those was discussed in detail.

- The Incentives for 4D BIM use was mostly influenced by external drivers such as competition and client’s demand. Large companies are seeking to maintain their strategic position within the industry while medium sized companies are still trying to realize the benefits.

- With regards to the solutions to overcome the barriers and to promote the widespread adoption of 4D BIM; developing 4D BIM standards, BIM mandate, improving software functionality and to conduct further research to clarify the benefits of 4D BIM are the most common solutions.

Based on findings, it is concluded that Swedish construction companies have started a journey towards 4D BIM implementation. Large Swedish construction companies seek to maintain their strategic position by incorporating advanced technologies into their organizations. While small to medium-sized companies are still lacking resources and are dependent upon client’s requirements. Overall the departure of this journey would be difficult unless comprehensive national BIM standards are developed; public sector initiate BIM mandates and software vendors launch supportive programs in enhancing 4D BIM awareness and develop their products based on users’ needs.

**Contribution and future research**

The results of this study could be used for industry professionals to understand the barriers and incentives which influence 4D BIM adoption, in order to develop strategies to mitigate barriers and to enhance the adoption rate. This in turn will promote sustainable practices in construction planning process (Olawumi and Chan 2018). Reducing waste, establishing an efficient logistics planning to reduce transportation during the production phase and avoiding re-work through visualizing construction process can help to achieve sustainability objectives. Realizing sustainability goals by using BIM is difficult unless organisations accept BIM and fully adopt it in their working practices (Bryde et al. 2013).

Since, this research was limited to a specific time and on a focused topic; some important aspects are left to be investigated further. Therefore, there is a need for an empirical case study to find the inter-organizational and project-related barriers that impede 4D BIM adoption. Moreover, as found out, there are difficulties in measuring the advantages of 4D BIM within companies, therefore, a study covering the cost-benefit analysis of 4D BIM application in monetary terms will be also interesting.


Johnson, R. E., and Laepple, S. E. (2003). Digital innovation and organizational change in design practice CRS Center, Texas A&M University

Kassem, M., Brogden, T., and Dawood, N. (2012). BIM and 4D planning: a holistic study of the barriers and drivers to widespread adoption. *Construction Engineering and Project Management*


Introduction:

Thank you very much for participating in this survey. My name is Mujtaba Sediqi and I am a second-year master student in Real Estate and Construction Management at KTH Royal Institute of Technology. The aim of this survey is to collect quantifiable data in order to answer the following research question for my master thesis, specialization in construction management: “What are the incentives and barriers which hinder / facilitate 4-Dimensional Building Information Modeling (4D BIM) adoption within Swedish construction companies?” by comparing small and medium-sized construction companies with large construction companies.

Prior to design this questionnaire, a literature study was conducted to identify the most cited variables that influence BIM and 4D BIM adoption within the Architecture Engineering and Construction (AEC) industry. Consequently, this questionnaire was designed to find out whether these variables are applicable within Swedish construction industry.

In order to draw a valid and precise conclusion, it is important for me to collect actual and real-life data. I therefore kindly request you to read the instructions and select the best answers which you think are applicable to you.

The information provided by you in this questionnaire will be used for research purposes only and will remain confidential. Only anonymized data will be published, and the data will not be used in a manner which would allow identification of your individual responses. Furthermore, your participation in this survey is entirely voluntary. You may refuse to take part in this study or exit the survey at any time.

Benefits: By taking part in this questionnaire, you will get a published copy of this research through email. On the other hand, your responses may help us learn more about 4D planning adoption status within Swedish construction firms, its advantages and the barriers which lead companies to decide to adopt or not to adopt it within their projects.

This questionnaire will take approx. 15 minutes of your time. I would like to thank you once again for your participation and dedicating your time to answer it.

Best regards

Mujtaba Sediqi
Student
KTH Royal Institute of Technology
sediqi@kth.se
0765684708

Supervisor: Prof. Vaino K. Tarandi - (KTH), Contact: vaino.tarandi@abe.kth.se

* Required

Outline

This questionnaire is divided into 6 sections based on the type of questions. Most of the questions are multiple choice, however there are some open-ended questions that require short answers too. The sections are as follows:

Section 1 – General Information decision process (Multiple choice & short answers)
Section 2 – Advantages of 4D planning vs traditional planning (Multiple choice)
Section 3 – The perceived characteristics of 4D BIM (Multiple choice)
Section 4 – 4D BIM usage (Multiple choice)
Section 5 – Barriers of 4D BIM adoption (Multiple choice)
Section 6 – Incentives/driving forces of 4D BIM adoption (Multiple choice)

General Information

Please answer the following questions which are needed for comparison purposes.
1. Company Name (Optional)


2. Position *


3. Email address (if you want to get the results of this study)


4. Company size *
   Mark only one oval.
   
   - Small (1-49 employees)
   - Medium-sized (50-500 employees)
   - Large (501+ employees)

5. In which of the following areas has your company been involved? Check all that apply *
   Check all that apply.
   
   - Buildings
   - Roads/Highways
   - Energy
   - Bridges
   - Defence infrastructure
   - Water
   - Railways
   - Airports
   - Harbors & ports
   - Water defence
   - Other:

6. Highest Educational Level *
   Mark only one oval.
   
   - High school diploma or lower
   - Bachelor's degree
   - Master's degree
   - Doctorate
7. How many years of experience do you have in Architectural, Engineering and Construction (AEC) industry? *
Mark only one oval.
- Less than 1 year
- 1-3 years
- 3-5 years
- 5-10 years
- 10 years or more

8. Do you currently use 4D BIM in your construction planning practices? *
Mark only one oval.
- Yes
- No

9. If "NO" Do you know anyone else in your organization who currently uses 4D BIM in their construction planning practices?
Mark only one oval.
- Yes
- No

10. Which of the following is applicable to you regarding BIM in general? *
Mark only one oval.
- A: I am aware of BIM and have used it
- B: I am aware of BIM but have not used it
- C: I am not aware of BIM After the last question in this section, stop filling out this form.

11. If you answered A or B, when did you hear about BIM for the first time? (i.e. 1990; 2000, 2012), write n/a if you answered C *

12. Which of the following is applicable to you regarding 4D BIM? *
Mark only one oval.
- A: I am aware of 4D BIM and have used it
- B: I am aware of 4D BIM but have not used it
- C: I am not aware of 4D BIM After the last question in this section, stop filling out this form.

13. If you answered A or B, when did you hear about 4D BIM for the first time? (i.e. 2000, 2012, 2014) write n/a if you answered C *
14. Have you ever used BIM in a project or been involved in a BIM-related project in any way? Check all that apply. *
   Check all that apply.
   - Yes, 3D BIM
   - Yes, 4D BIM
   - Yes, 5D BIM
   - None of the above
   - Other: ______________

15. If you answered "YES", when did you start using any of the BIM functions for the first time? (Approx. year e.g. 2000, 2012), write n/a if you have chosen any other option *

16. If you are NOT using BIM 4D in your organization, when do you think you will start using it?
   Mark only one oval.
   - Within 1-3 years
   - Within 3-5 years
   - Within 5-10 years
   - Over 10 years
   - Not sure
   - Never

17. Competency level *
   Mark only one oval per row.
   - How do you rate your BIM proficiency in general?
     - Poor
     - Fair
     - Satisfactory
     - Advanced
     - Expert
   - How do you rate your 4D BIM proficiency?
     - Poor
     - Fair
     - Satisfactory
     - Advanced
     - Expert

Decision

In this section, we need to know how decisions are made to adopt/not adopt BIM 4D within your organizations. Please choose the answer which best describes your organization. If not applicable, leave it unchosen

18. Has any decision been made to adopt or reject the use of 4D BIM for the planning of construction work at your organization yet? *
   Mark only one oval.
   - Yes
   - No
19. What was the decision? *  
Mark only one oval.  
- Decision to adopt 4D BIM  
- Decision to Reject 4D BIM  
- No Decision/undecided  

20. If the decision was to "Adopt 4D BIM" which type of decision was it?  
Mark only one oval.  
- Optional (individual)  
- Top-down (authority) decision  
- Collective decision  
- Other:  

21. If the decision was to "Reject 4D BIM" adoption which type of decision was it?  
Mark only one oval.  
- Optional (individual)  
- Top-down (authority) decision  
- Collective decision  
- Other:  

Communication Channels  

22. Which of the following communication channels do you prefer to use to obtain information about 4D BIM technology? *  
Mark only one oval.  
- External Sources (Mass media including websites, journals, magazines; government)  
- Internal sources (Colleagues, peers, workmates or interpersonal networks)  

23. Personally, which of the following communication channels has had/would have more influence in deciding to adopt or reject the use of 4D BIM technology? *  
Mark only one oval.  
- External (Mass media including websites, journals, magazines; government)  
- Internal (Colleagues, peers, workmates or interpersonal networks)  

Perceived advantages  
In this section we would like to examine the advantages of 4D BIM from two different angles of construction planning (Functions and Process). The construction planning function refers to the required output of planning process. The construction planning process refers to those activities that are carried out by the planners when they plan. For this reason, we need to compare both the process and the functions of 4D planning method with traditional methods.
In your opinion, how do you rate the relative advantages of 4D BIM FUNCTIONS over traditional construction planning practices?*

Mark only one oval per row.

<table>
<thead>
<tr>
<th>Function</th>
<th>1 - Much worse than traditional</th>
<th>2 - Worse than traditional</th>
<th>3 - Same as traditional</th>
<th>4 - Better than traditional</th>
<th>5 - Much better than traditional</th>
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<tbody>
<tr>
<td>Visualizing the construction process</td>
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<td>Simplifying the understanding of the construction process</td>
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<td>Logistics planning (equipment and material flow to, within and from construction site)</td>
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<td>Planning and coordinating working space</td>
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<td>Site layout planning (Locating)</td>
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<td>Design interrogation</td>
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<td>Planning construction approaches (comparison of execution plans)</td>
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<td>Validating the time schedule</td>
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<td>Safety planning (i.e. scaffold; emergency response; crane)</td>
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<td>Location-based planning</td>
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<td>Work progress reporting</td>
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</table>
25. In your opinion, how do you rate the relative advantages of 4D BIM over traditional construction planning PROCESS elements *
Mark only one oval per row.

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<thead>
<tr>
<th></th>
<th>1 - Much worse than traditional</th>
<th>2 - Worse than traditional</th>
<th>3 - Same as traditional</th>
<th>4 - Better than traditional</th>
<th>5 - Much better than traditional</th>
</tr>
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<tbody>
<tr>
<td>Communicating the construction plan</td>
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<td>Planning the construction sequence</td>
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<td>Organizing the logical dependencies</td>
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<td>Communicating project timescales</td>
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<td>Identifying activities</td>
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<td>Collecting information</td>
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<td>Calculating activity duration</td>
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The perceived characteristics of 4D BIM
In this section we would like to examine the perceived attributes linked with an innovation, in our example ‘4D BIM’. These attributes are compatibility, complexity, trialability and observability. The following questions are designed to reflect all of the four attributes.

26. Please state how much do you agree or disagree with the following statements regarding the characteristics of 4D BIM? *
Mark only one oval per row.

The use of 4D BIM is compatible with our current practice of construction planning

4D BIM methods would be difficult to learn

4D BIM methods would be difficult for planners to understand

The training required in order to learn 4D BIM methods would be complicated

4D BIM methods would have to be experimented with before using to plan real construction work

It is easy to see the impact that 4D BIM has on construction planning effectiveness

4D BIM usage
In this section we would like to understand the extent that 4D BIM approach was used and will be used for different activities.
27. If you have used or been involved in a project using 4D BIM, to what extent did you use it for the following activities? *

Mark only one oval per row.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Never</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Often</th>
<th>Always</th>
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<tbody>
<tr>
<td>Visualizing the construction flow</td>
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<td>Validating and analysis of the time schedule</td>
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<td>Safety planning (i.e. scaffold; crane)</td>
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<td>Work progress reporting</td>
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</table>

28. If other, please specify

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**Barriers to 4D BIM adoption**

This section is dedicated to examining the barriers which hinder 4D BIM adoption. Please state the strength of your agreement/disagreement for each of these barriers which you think has influence on 4D BIM adoption.
29. In your opinion, to what extent do you agree/disagree with the following statements as the major constraints to implement 4D BIM in your company? *  
*Mark only one oval per row.*

<table>
<thead>
<tr>
<th>Lack of demand from the client side to use 4D BIM</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Our partners (other firms) do not use 4D BIM</td>
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<tr>
<td>No internal demand in the company to use 4D BIM</td>
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<tr>
<td>High costs to invest in hardware</td>
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<td>High costs to invest in software</td>
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<tr>
<td>High costs for training</td>
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<tr>
<td>Lack of 4D BIM knowledge within internal workforce</td>
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<tr>
<td>Lack of 4D BIM expertise in the market</td>
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<tr>
<td>Lack of client knowledge about 4D BIM</td>
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<tr>
<td>Not worth time investment to learn</td>
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<tr>
<td>Lack of time for employees to learn</td>
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<tr>
<td>The lengthier process of 4D BIM creation</td>
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<tr>
<td>Difficulty in understanding 4D BIM methods</td>
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<tr>
<td>The complicated training process of 4D BIM</td>
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<td>Difficult to find people with the required skills</td>
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<td>Employee resistance to change from traditional construction planning practices to 4D BIM</td>
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<tr>
<td>Incompatible with current organizational culture</td>
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<tr>
<td>Does not give any clear competitive advantages</td>
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<tr>
<td>Difficulty in measuring the advantages of 4D BIM</td>
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<tr>
<td>Lack of tangible benefits of 4D BIM/business value</td>
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<tr>
<td>Traditional project delivery methods/contract</td>
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<tr>
<td>Legal problems within BIM-supported projects</td>
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<tr>
<td>The large variety of commercial software make it difficult to choose</td>
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<tr>
<td>Problems with exchanging data between software</td>
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<tr>
<td>Lack of standards for 4D BIM</td>
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</tbody>
</table>

30. Please specify, if you think there are more constraints

**Incentives/Driving forces**

This section is dedicated to examine the driving forces which incentivize individuals to implement 4D BIM in their organizations. Please state the strength of your agreement/disagreement for each of these driving forces which you think has influence on 4D BIM implementation.
31. **To what extent do you agree/disagree with the following statements as driving forces to implement 4D BIM in your company?**

*Mark only one oval per row.*

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>By using BIM we can follow the technical development</td>
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<tr>
<td>We know that 4D BIM should give us competitive advantages</td>
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<tr>
<td>We have enough internal expertise capacity to implement 4D BIM</td>
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<tr>
<td>We believe that 4D BIM innovation would be of strategic importance for the company</td>
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<tr>
<td>We get good support from external actors/consultants to use 4D BIM in our projects</td>
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<tr>
<td>It is straightforward and easy to adopt and use 4D BIM</td>
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<td>All our partners and competitors use 4D BIM</td>
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<td>We perceive a strong internal demand for 4D BIM</td>
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<td>4D BIM was a clear requirement from our clients</td>
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<tr>
<td>4D BIM diminishes risks by reducing onsite conflicts and change orders.</td>
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<tr>
<td>4D BIM helps to expedite the decision making process</td>
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</tbody>
</table>

32. **Please specify if there are more driving forces which are not mentioned above**

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**Solutions/drivers to use 4D BIM**

In this part we want to know what are the drivers/solutions that can influence your decision to adopt 4D BIM in your company. If you think there are more solutions except those listed below, we will highly appreciate to specify them in the last part of this section.
33. **To what extent are the following solutions/drivers IMPORTANT for your organization to adopt 4D BIM?** *

Mark only one oval per row.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Very low</th>
<th>Low</th>
<th>Neutral</th>
<th>High</th>
<th>Very High</th>
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</thead>
<tbody>
<tr>
<td>Public sector mandate 4D BIM as a requirement in all construction projects</td>
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<tr>
<td>We receive good support from software vendors (i.e. training, extended trial period, low price)</td>
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<tr>
<td>Our partners start using 4D BIM</td>
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<tr>
<td>The internal authority level required 4D BIM</td>
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<tr>
<td>Lower costs for software and hardware</td>
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<td>4D BIM become a standard in all projects</td>
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<tr>
<td>When we realized clear benefits of 4D BIM</td>
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34. **If other, please specify**

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33. **To what extent are the following solutions/drivers IMPORTANT for your organization to adopt 4D BIM?** *

Mark only one oval per row.

<table>
<thead>
<tr>
<th>Solution</th>
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</table>

34. **If other, please specify**

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Appendix II

Interview questions

Before starting interview, the research topic was briefly described to each interviewee and then the consent form was signed by both sides.

The opening questions for each topic of research are listed below. However most of the questions in interview were follow up questions which were formulated differently based on the answers from respondents. The follow up questions are not listed here.

- Do you use 4D BIM in your company?
- Do you use it in all of your projects?
- Do you know about BIM maturity level? What level do you think your company is in?
- Do you have any strategy for implementing 4D BIM in the future?
- When do you think you will fully adopt 4D BIM?
- Who takes decision to implement 4D or similar technologies?
- Which function of 4D BIM do you use the most and which functions the less? And why?
- What are the advantages of 4D BIM that you cannot find in traditional construction planning and vice versa?
- Which of the construction planning methods do you prefer and why?
- What is not good in 4D BIM? And what is not good in conventional methods
- Have you ever observed and measured the benefits of 4D BIM?
- Do you think if 4D BIM is compatible with your current organization and construction planning practices?
- Do you think if 4D BIM is complicated to learn, to use, and to teach?
- Have you tried or currently testing 4D BIM before using it?
- How do you compare your expectation before using and your satisfaction after using 4D planning?
- In your opinion what are the main challenges and barriers for 4D BIM implementation in your company?
- Which barriers are the most severe? And what are the most influential factors?
- Are you happy with the 4D BIM tools available in the market?
- How was the organizational transformation process from conventional construction planning to 4D planning?
- Why do you use 4D BIM? What are the strong motives and incentives behind it?
- Do you use 4D BIM by your own or as per client’s request?
- Do you think 4D BIM can deliver sustainable project management process and help sustainability in any way?
- What are the best solutions in your opinion to overcome the barriers in 4D BIM adoption? It can be from your organization or from external parties.